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AN INVESTIGATION OF USING A VIRTUAL TARGET FOR AIR-TO-AIR TRACKING HANDLING QUALITIES (HQ) EVALUATION (HAVE TRACK)

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FINAL REPORT

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This technical report presents the results of the Investigation of Using a Virtual Target for Air-to-Air Tracking Handling Qualities (HQ) Evaluation (HAVE TRACK). The objective of the project was to evaluate the use of flight test head-up display (HUD) tracking tasks as a replacement for the aircraft tracking tasks currently used to evaluate HQ. Specifically, air-to-air tracking tasks were evaluated to determine if a target aircraft could be replaced with a HUD generated target. Results obtained from numerical HQ prediction methods were compared with the results obtained during actual air-to-air target tracking.

In addition to the investigation of HUD tracking task fidelity and numerical HQ prediction methods, this project investigated numerical methods for determining HQ ratings and measuring pilot workload. This project evaluated the use of the power spectral density (PSD) of a pilot's input to the aircraft as a measure of pilot physical workload during tracking tasks. The project evaluated the effect of a learning curve on a pilot's workload. The evaluation was based on the examination of the PSD of the pilot input during successive attempts at the three tracking tasks.

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Cooper-Harper rating, head-up display, HQ, HUD, learning curve, pilot-induced oscillation, R. Smith Criteria

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PREFACE

This technical report presents the results of the Investigation of Using a Virtual Target for Air-to-Air Tracking Handling Qualities (HQ) Evaluation (HAVE TRACK). The objective of the project was to evaluate the use of flight test head-up display (HUD) tracking tasks as a replacement for the aircraft tracking tasks currently used to evaluate HQ. Specifically, air-to-air tracking tasks were evaluated to determine if a target aircraft could be replaced with a HUD-generated target. In addition, results obtained from numerical HQ prediction methods were compared with the results obtained during actual air-to-air target tracking. The F-16 Variable Stability In-flight Simulator Test Aircraft (VISTA) was used as the test aircraft, and a T-38 support aircraft was used as a target.

Tests were conducted by the USAF Test Pilot School HAVE TRACK Test Team at the Calspan test complex in Buffalo, New York, from 15 through 24 March 1999. The project was sponsored by the USAF Test Pilot School as part of the school's curriculum and supported by the Air Force Research Laboratory.

The authors would like to thank Messrs. Russell Easter, Jeffrey Peer, Karl Hutchison, and Thomas Landers of Calspan and Ralph Smith of High Plains Engineering for their consistently outstanding support during the planning, conduct, and reporting of this program.

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EXECUTIVE SUMMARY

This technical report presents the results of the Investigation of Using a Virtual Target for Air-to-Air Tracking Handling Qualities (HQ) Evaluation (HAVE TRACK). The objective of the project was to evaluate the use of flight test head-up display (HUD) tracking tasks as a replacement for the aircraft tracking tasks currently used to evaluate HQ. In addition, results obtained from numerical HQ prediction methods were compared with the results obtained during actual air-to-air target tracking. All test objectives were met.

Tests were conducted by the USAF Test Pilot School (TPS) HAVE TRACK Test Team at the Calspan test complex in Buffalo, New York, from 15 through 24 March 1999. The test team performed 1 verification flight (1.3 hours) and 9 test flights (10.5 hours) in the F-16 Variable Stability In-flight Simulator Test Aircraft (VISTA). Prior to the test team sorties, Calspan flew two checkout sorties to ensure proper aircraft function. The project was sponsored by the USAF TPS as part of the school's curriculum and supported by the Air Force Research Laboratory. This project was conducted under the authority of the Commandant, USAF TPS.

The test items for the HAVE TRACK test project were two HUD tracking tasks programmed on the F-16 VISTA. The first HUD task was of high fidelity and was developed to closely mimic an actual air-to-air target. The second HUD task was of lower fidelity and corresponded to tasks contained in MIL-STD-1797A. For each of the two HUD tasks, the test aircraft was evaluated with three different FCCs. The first configuration was a predicted level 1 aircraft and the second and third configurations were degraded versions of this level 1 aircraft (one with increased control stick sensitivity and one with added time delay).

In addition to the investigation of HUD tracking task fidelity and numerical HQ prediction methods, this project investigated numerical methods for measuring pilot workload. The project evaluated the use of the power spectral density (PSD) of a pilot's input to the aircraft as a measure of pilot physical workload during tracking tasks. In addition, the project evaluated the effect of a learning curve on a pilot's workload. The evaluation was based on the examination of the PSD of the pilot input during successive attempts at the three different tracking tasks. The learning curve/PSD investigation was performed for each combination of the three tracking tasks and the three aircraft FCCs.

The HUD tasks, combined with handling qualities during tracking (HQDT), were successful in predicting pilot-induced oscillation (PIO) susceptibility. The HUD tracking tasks were also instrumental in identifying a lack of standardized maneuvers among the pilots. However, the HUD tasks did not reliably predict pilot ratings during operational tasks.

Except in cases where stick sensitivity was the source of PIO, predictions from the R. Smith Criteria correlated well with pilot ratings following HQDT maneuvers. The R. Smith Criteria were, however, a poor predictor of pilot ratings during operational tracking tasks.

Pilot bandwidth, as defined in this report, during Phase 3 operational tracking tasks relative to pilot bandwidth during HQDT maneuvers did not provide a measure of pilot physical workload suitable for use in HQ evaluations.

The use of HUD tracking tasks eliminated the need to organize maneuvers between multiple aircraft. This increased the percentage of flight time spent on data collection by 33 percent.

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INTRODUCTION

GENERAL

Head-up display (HUD) tracking tasks, which simulate air-to-air engagements, of varying fidelity were tested on the NF-16D Variable Stability In-Flight Simulator Test Aircraft (VISTA). Throughout this test project, the results were compared with those obtained during tracking of an actual air-to-air target.

Tests were conducted by the USAF Test Pilot School (TPS) HAVE TRACK Test Team at the Calspan test complex in Buffalo, New York, from 15 through 24 March 1999. The test team performed 1 verification flight (1.3 hours) and 9 test flights (10.5 hours) using the F-16 VISTA. Prior to the test team sorties, Calspan flew two checkout sorties to ensure proper aircraft function. The project was sponsored by the USAF TPS as part of the school's curriculum and supported by the Air Force Research Laboratory. This project was conducted under the authority of the Commandant, USAF TPS.

BACKGROUND

The main objective of this project was to evaluate the use of flight test HUD tracking tasks as a replacement for the aircraft tracking tasks currently used to evaluate handling qualities (HQ). Throughout this test project two pilot ratings scales for HQ were used. The Cooper-Harper rating (CHR) scale (Figure B1) was used to describe the HQ of an aircraft during a specified tracking task. The pilot-induced oscillation (PIO) tendency scale (Figure B2) was used to describe the susceptibility of an aircraft to enter a PIO rating (PIOR). Further details on these rating scales can be found in Reference 1.

The fidelity of HUD tracking tasks can be varied on flight test aircraft. These HUD tasks could provide a cost-effective way of obtaining HQ data because they do not require support aircraft during tracking tasks. The HUD tracking task also allows tracking error to be easily measured for later data reduction. Areas where HQ could be investigated using HUD tracking tasks include air-to-ground tracking, air-to-air tracking, aerial refueling, formation, and landing tasks.

This project investigated the level of fidelity required in the HUD tracking task to obtain HQ ratings similar to those obtained using an actual air-to-air target. Two levels of fidelity were evaluated. First, the high-fidelity tracking task attempted to match HUD target motion to that of a maneuvering aircraft. Second, the low-fidelity tracking task was obtained from MIL-STD-1797A (Reference 1).

In addition to the pilot ratings for aircraft HQ, the R. Smith criteria (References 2 through 5) was used to predict aircraft HQ. Numerical methods were also used to evaluate task performance and pilot workload independent of the HQ evaluation methods. These numerical methods results were compared with those obtained from pilot comments and ratings during tracking tasks.

The handling qualities during tracking (HQDT) piloting technique required the evaluation pilot to aggressively track a precision aimpoint on a target, assiduously correcting even the smallest tracking errors. When using this technique the pilot would drive the aimpoint to the target as quickly as possibly without "shaping" the stick inputs as zero error was approached and would reverse command only after zero error was reached. A graphical example of the technique is presented in Figure 1. Using this technique, pilot stick inputs would be driven at the pilot's highest possible input frequency. The HQDT task was an attempt to eliminate pilot compensation and force the pilot to fly at his maximum bandwidth. Through HQDT tasks, the pilot-in-the-loop system stability could be examined under the highest possible pilot bandwidth. This was one method used to determine pilot-in-the-loop oscillation susceptibility of an aircraft. The standardization of the HQDT technique used by each project test pilot is further described in Appendix G.

The power spectral density (PSD) of the pilot's input was the power content of the pilot's input as a function of frequency. For the purposes of this report, bandwidth with respect to PSD is the range of frequencies within which the PSD curve differs from the peak value of the PSD by less than one order of magnitude. The relatively high frequency inputs that occured during HQDT tasks should result in a higher pilot bandwidth than was seen in ordinary tracking tasks. It was proposed that the PSD of the pilot's control input could be used as a measure of physical workload during tracking tasks. If a tracking task was repeated multiple times in succession, the pilot workload should have decreased as experience was gained.

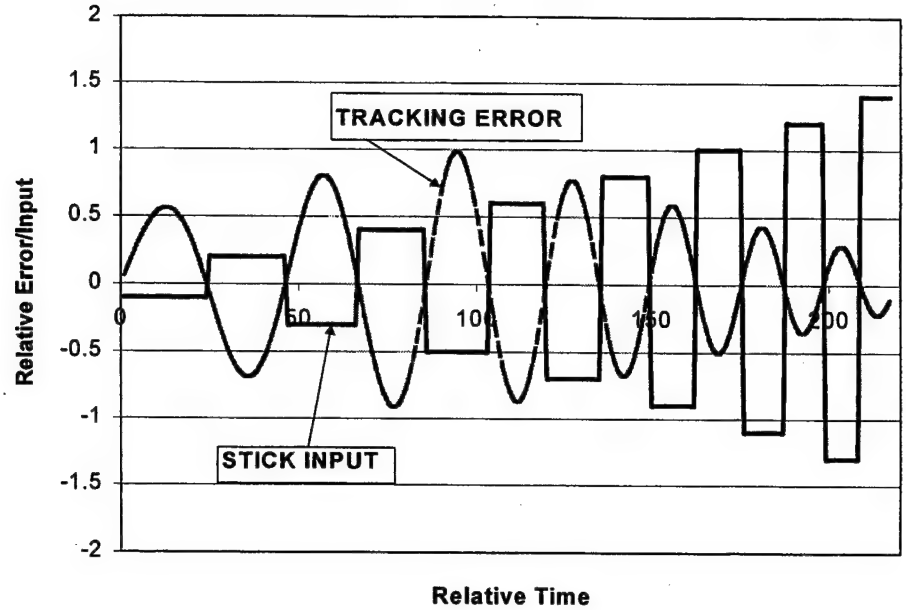


Figure 1 Notional Pilot Control Input During a Handling Qualities During Tracking Maneuver

(i.e., a learning curve). If the PSD could be used to estimate pilot workload, then this provided a tool that could be used to backup pilot comments and ratings.

PROGRAM DESCRIPTION

Head-up display tracking tasks could be implemented at various levels of fidelity, with increasing fidelity coming at the cost of increased programming effort. This project compared the HQ results obtained during tracking an actual air-to-air target with the results obtained by tracking HUD targets of two different fidelity levels. These three tracking tasks were performed using three different aircraft flight control configurations (FCCs) implemented on the Calspan variable stability system (VSS) currently installed on the F-16 VISTA. The three aircraft FCCs flown represented one level 1 aircraft and two degraded FCCs.

In addition to the investigation of HUD tracking task fidelity, this project investigated numerical methods for evaluating HQ and pilot workload. In particular, the R. Smith Criteria was used and its predicted PIOR and HQ rating (HQR) of the three aircraft FCCs (baseline, sensitive stick, and time delay configurations) were compared with results obtained during actual tracking of a target aircraft.

In order to determine the validity of the PSD estimate of pilot workload, this project computed the PSD of the pilot input during successive attempts at performing the three tracking tasks described above. This learning curve/PSD investigation was performed for each of the three aircraft FCCs described above. In addition, for each tracking task and each aircraft FCC, HQDT testing was performed to determine an upper boundary for pilot physical workload.

TEST ITEM DESCRIPTION

The test items for the HAVE TRACK test project were two HUD tracking tasks programmed on the F-16 VISTA. The first HUD task was of high fidelity and was developed to closely mimic an actual air-to-air target. The second HUD task was of lower fidelity and corresponded to tasks contained in MIL-STD-1797A (Reference 1). For each of the two HUD tasks, the test aircraft was used to simulate three different aircraft. The test aircraft simulated a predicted level 1 aircraft and two degraded versions of this level 1 aircraft (one with added time delay and one with increased control stick sensitivity.) See Appendix A for further details on the aircraft FCCs. See the Test Resources section for further information on the HUD tracking tasks.

TEST OBJECTIVE

The test objective was to evaluate the use of flight test HUD tracking tasks as a replacement for the aircraft tracking tasks currently used to evaluate HQ. Specifically, air-to-air tracking tasks used to determine HQ were evaluated to determine if a

target aircraft could be replaced with a HUD target. Numerical methods for determining HQ and pilot workload were also investigated and the results compared with those obtained during flight test. Learning curve effects were investigated through examination of the task performance results and PSDs obtained after repeating the same tracking task multiple times in succession.

LIMITATIONS

Due to funding limitations, it was not possible to detail the timing of all instrumentation signals installed on the F-16 VISTA. It was possible that an unknown amount of time delay existed between data signals used for recording the aircraft and pilot performance.

Also, a programmed test input was not available in the F-16 VISTA for this test program. Therefore, pilots were required to perform frequency sweeps manually to gather data for the numerical methods.

TEST RESOURCES

Target Profiles:

For all tracking tasks a flight test programmable HUD was used. The HUD layout was similar to the standard F-16 cruise HUD. It contained altitude, airspeed, pitch ladder, g-loading, and magnetic heading. The flight path marker could be blanked. The standby reticle included a 25, 10, and 5 milliradian (mil) radius circle. The depression of the reticle was 35 mils and was chosen to minimize lateral-directional 'pendulum' effects. The depression of the reticle was fixed throughout the test program. The HUD-generated target resembled a center dot with two wings commanding both pitch and bank. Further details on the HUD symbology are shown in Figure 2.

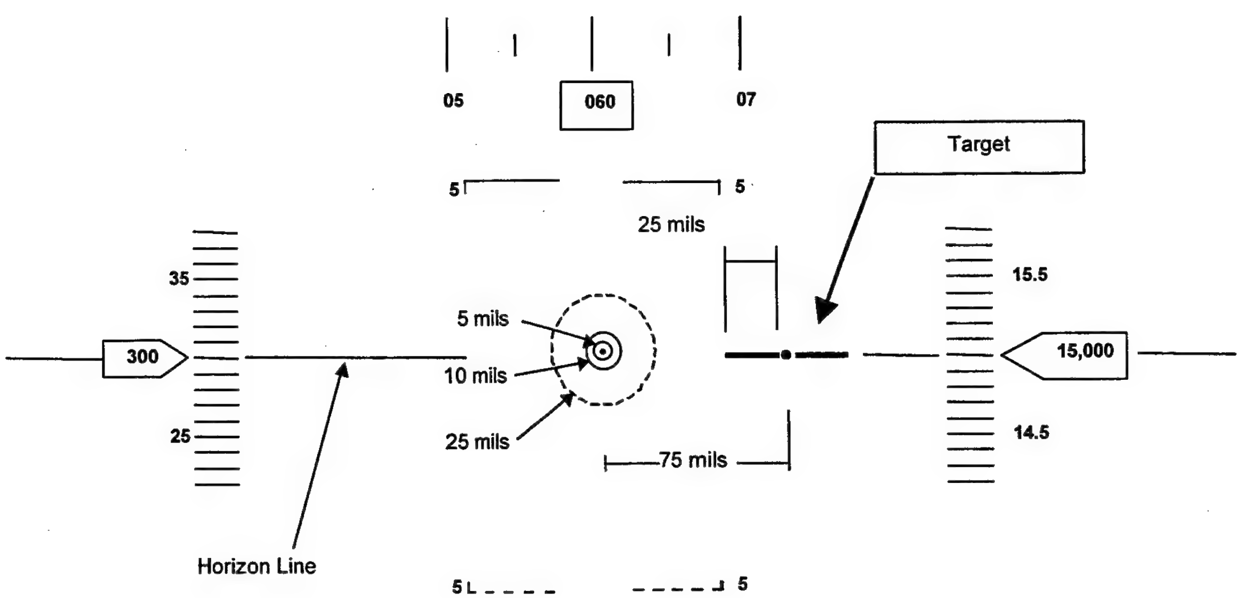


Figure 2 Head-Up Display (HUD) Depiction

The target tasks included an actual target (T-38 aircraft) profile and two different HUD target profiles. The first HUD profile (high-fidelity HUD task) was an operationally representative altitude stabilized target in a level turn at a constant load factor. This task was designed to mimic the actual target profile. The second HUD profile (low-fidelity HUD task) was obtained from MIL-STD-1797A (Reference 1).

Tracking Task No. 1, Actual Target.

The actual target was at 15,000 feet pressure altitude (PA), 0.75 Mach, 2,000 feet in front of the test aircraft, and offset 75 mils to the right. On command, the target began a 3-g level turn to the right for 10 seconds. Roll-in took approximately 1 second. After 10 seconds, the T-38 aircraft began an unloaded reversal to a 3-g turn to the left. The reversal took approximately 2 seconds. The target continued turning until the test aircraft called terminate. The turn rate was approximately 6 degrees per second. Figure 3 shows the setup conditions for the actual target tracking task.

Tracking Task No. 2, High Fidelity HUD.

Tracking task No. 2 mimicked the actual target motion presented by the actual T-38A target aircraft. To accomplish this, the HUD target commanded level turns. The target commanded a constant turn rate stabilized at a constant altitude. The target rolled to a bank angle that approximates a 3-g turn (71 degrees of bank). The target started wings level 75 mils offset right from aircraft heading (Figure 2). On command, the target rolled to 71 degrees of right bank and commanded a heading change to the right increasing from 0 degrees per second to 6 degrees per second in one second. The target continued to command a 6 degrees per second heading change for 10 seconds. The target then rolled left to 71 degrees left bank and the heading change rate changed from 6 degrees per second right to 6 degrees per second left within 2 seconds. The target continued to command a heading change to the left until the simulation was stopped. Changes in target bank angle and heading change were linear. Figures 4 and 5 show time traces of the high-fidelity HUD task.

Tracking Task No. 3, Low Fidelity HUD.

Tracking task No. 3 included both longitudinal and lateral body axes profiles and is shown in Figures 6 and 7.

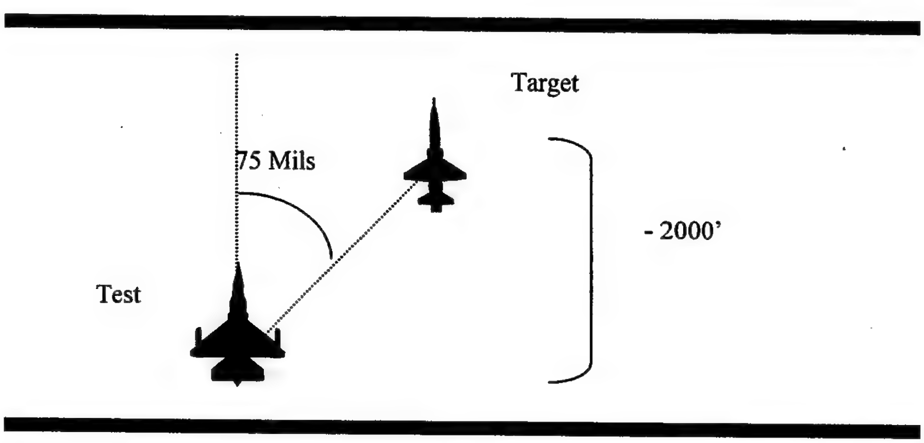


Figure 3 Tracking Task No. 1 Setup, Actual Target

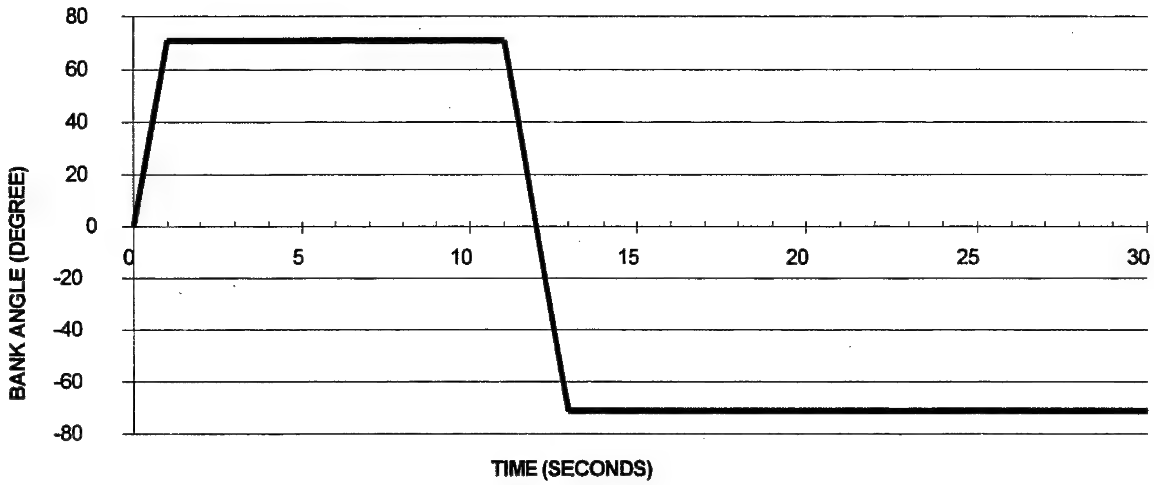


Figure 4 Tracking Task No. 2, Head-Up Display Target Bank Angle

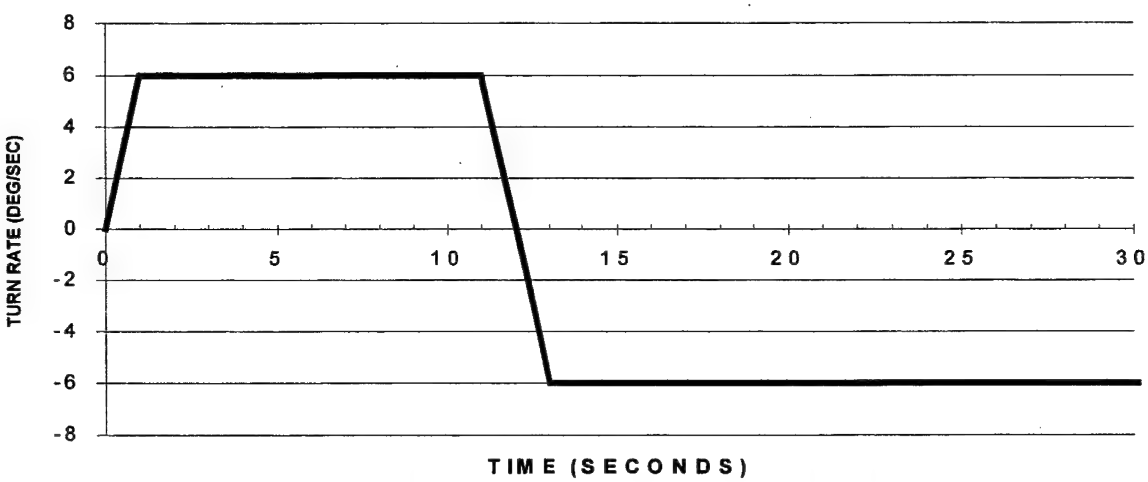


Figure 5 Tracking Task No. 2, Head-Up Display Target Turn Rate

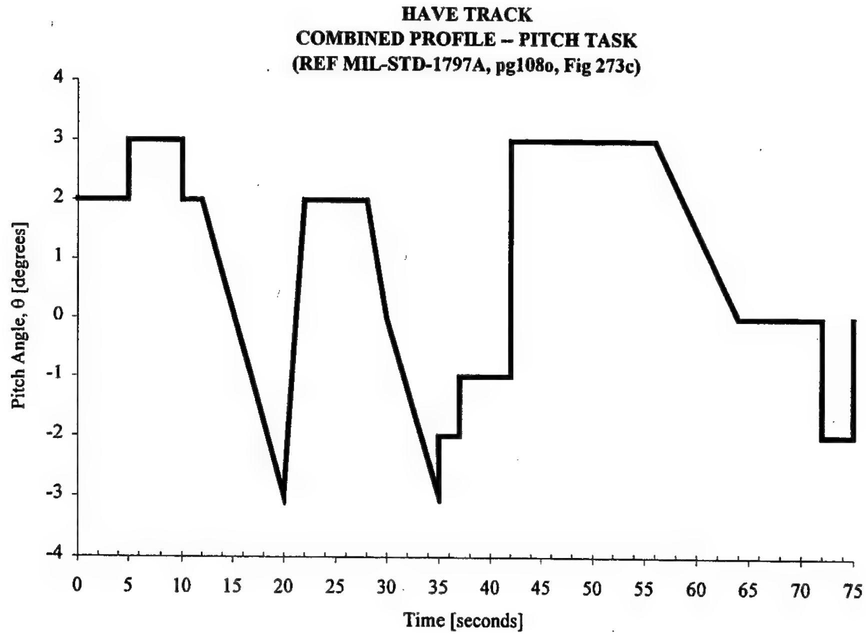


Figure 6 Tracking Task No. 3, Head-Up Display Target Pitch Axis ($K_{TASK\_PITCH} = 1$)

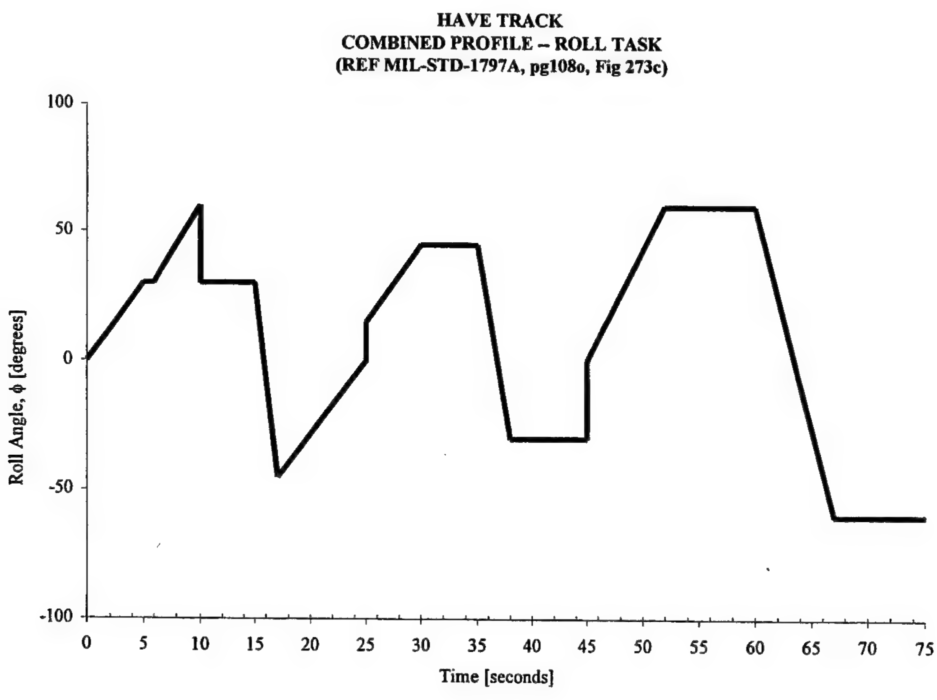


Figure 7 Tracking Task No. 3, Head-Up Display Target Roll Axis ($K_{TASK\_PITCH} = 1$)

TEST FACILITIES

All flights were flown from the Calspan complex in Buffalo.

TEST AIRCRAFT

The test aircraft, NF-16D VISTA USAF S/N 86-0048, was owned by the Air Force Research Laboratory and operated and maintained by Calspan. The VISTA was a modified Block 30 NF-16D aircraft powered by an F100-PW-229 engine. The front cockpit included several VSS control panels, a removable variable feel center stick controller, and a variable feel side stick controller. Most of the basic aircraft switches and controls were moved to the rear cockpit. The rear cockpit used conventional F-16 controls except that the throttle was driven by a servo system when the VSS was in use. The primary VSS controls and displays were also located in the rear cockpit. The hydraulic system was enhanced with increased capacity pumps, lines, and high-rate actuators for the flaperons and horizontal tails.

The analog flight controls system was replaced with a modified Block 40 Digital Flight Control System which incorporated the interface for the VSS. The VSS generated signals to operate the flight controls using a virtually unlimited set of command gains that could be changed in flight. The system consisted of three Hawk computers that generated the commands for the flight controls, a feel system computer which controlled the feel for the front cockpit center stick and side stick, and a Raymond disk which stored preprogrammed sets of gains and control laws for VSS operation. More detailed information can be found in the VISTA Partial Flight Manual (Reference 6).

The F-16 VISTA was equipped with over 100 safety trips that disengaged the VSS to prevent the aircraft from escaping from the operational envelope. The VISTA operational envelope is shown in Figure 8.

These safety trips were designed to prevent departure of the aircraft and to prevent structural damage from occurring. Three different aircraft FCCs were required for completion of this test project. Flight tests were performed with the aircraft center stick only. The first test aircraft FCC was a baseline aircraft derived from FCCs previously flown during the HAVE FILTER project (Reference 7). The second test aircraft FCC was a degraded aircraft developed by increasing the stick sensitivity of the baseline aircraft. The third test aircraft FCC was a degraded aircraft developed by adding time delay to the baseline aircraft. Calspan was responsible for implementing these FCCs. These FCCs were verified during the Calspan calibration flights and remained fixed for all remaining test sorties. Further descriptions of these configurations are contained in Appendix A.

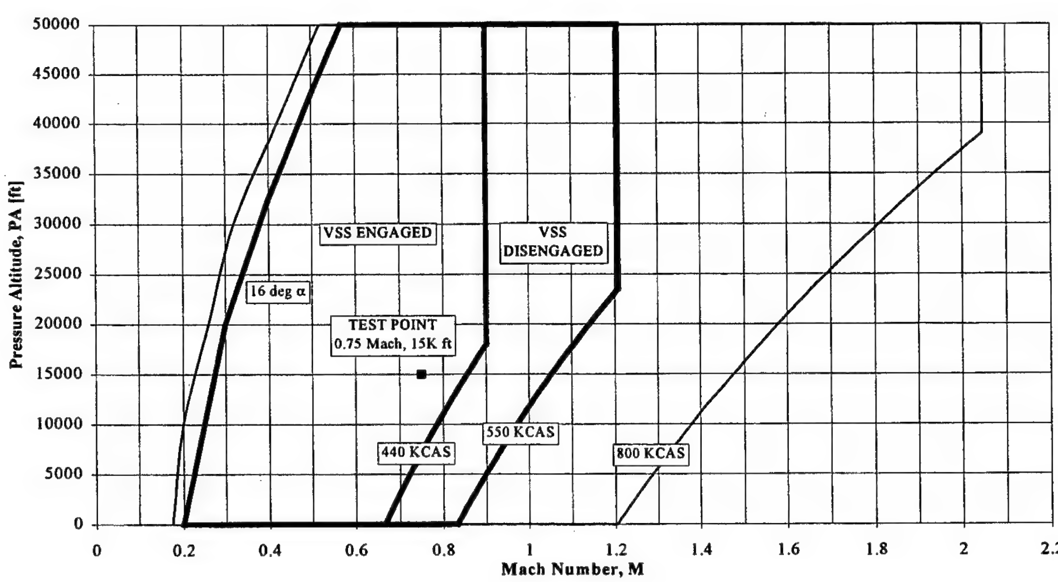


Figure 8 F-16 Variable Stability In-Flight Simulator Test Aircraft (VISTA) Operational Envelope

SUPPORT AIRCRAFT

A T-38 target aircraft was required for three of the nine VISTA test sorties. The target aircraft was used to perform the maneuvers described in the previous sections. The T-38 aircraft was selected because it was relatively inexpensive and had the capability to perform the 3-g turns required during the HQ evaluations tested under this project. The aircraft was deployed to Buffalo, from Edwards AFB, California. The T-38 aircraft was in a clean cruise configuration for all target sorties.

TEST RANGE

Formation flights were conducted in a military operating area (MOA). The Misty MOA was used for these formation test flights.

INSTRUMENTATION REQUIREMENTS

The test aircraft was capable of storing more than 60 digital signals and numerous analog signals. Parameters of interest were recorded via the on-board data acquisition system and downloaded postflight. Telemetry was not required. Instrumentation requirements are described in the Instrumentation Plan, Appendix C.

TEST AND EVALUATION

GENERAL

The objective of the HAVE TRACK flight test was to gather data to evaluate the use of flight test HUD tracking tasks as a replacement for the aircraft tracking tasks currently used to predict aircraft HQ. Data from air-to-air tracking tasks were evaluated to determine if a target aircraft can be replaced with a HUD target.

Flight testing was conducted at the Calspan complex in Buffalo, New York, from 15 through 24 March 1999. The test team performed 1 verification flight (1.3 hours) and 9 test flights (10.5 hours) in the F-16 VISTA. Prior to the test team sorties, Calspan flew two checkout sorties to ensure proper aircraft function. All testing was conducted at 15,000 feet pressure altitude and at 0.75 Mach. Three FCCs were tested:

1. Baseline aircraft.
2. Baseline aircraft with increased stick sensitivity.
3. Baseline aircraft with added time delay.

Three test pilots were used to evaluate each combination of FCC and tracking task. The pilots were highly experienced, but had different operational backgrounds. The background and experience level of each pilot is presented in Table 1. The flight test results matrix can be found in Appendix E.

Table 1
PROJECT TEST PILOT BACKGROUND AND EXPERIENCE LEVEL

Report Designator	Aircraft Flown	Flight Hours
Pilot A	T-38	1,200
	B-1	1,200
Pilot B	T-38	140
	F-16	1,900
Pilot C	T-38	400
	C-130	3,000
	U-2	400

TEST OBJECTIVES AND MEASURES OF PERFORMANCE

The specific HAVE TRACK project test objectives and the associated measures of performance (MOPs) were:

1. Evaluate the required fidelity for a virtual target.

   a. MOP 1.1: PIORs During HQDT.

   b. MOP 1.2: Pilot ratings during operationally representative tracking.

   c. MOP 1.3: Effective time delay in the VISTA flight test HUD.

2. Evaluate numerical methods as a backup for pilot ratings.

   a. MOP 2.1: Numerical methods for PIORs.

   b. MOP 2.2: Numerical methods for HQRs.

3. Evaluate analytical methods for showing learning curve.

   a. MOP 3.1: Analytical methods versus pilot ratings.

The following sections describe the results obtained for these objectives and MOPs in detail. Please note: Throughout the course of this report it was necessary to compare multiple PIORs and CHRs. Where there was more than one set of data from which to generate ratings (most situations), an average rating is shown. Most ratings numbered in excess of 10 sets of data, so the average is used to condense and simplify the results. In each case where multiple ratings are presented, the error bars shown in the figures denote the maximum and minimum ratings given. The error bars are not statistical in nature. For every maneuver presented, the detailed data can be found in Appendix E.

Objective 1: Evaluate the Required Fidelity For A Virtual Target:

Test objective 1 was met. All MOPs were evaluated and the procedures and results of these evaluations are presented below. The goal of

this objective was to determine if PIORs and CHRs given after tracking a HUD generated target adequately matched those given after tracking an actual aircraft.

There were three MOPs associated with this objective: PIORs during HQDT, pilot ratings during operationally representative tracking, and effective time delay of the flight test HUD.

MOP 1.1 – PIORs During HQDT.

This MOP compared the PIORs obtained during performance of HQDT on an actual air-to-air target aircraft to the PIORs obtained during HQDT on HUD-generated virtual targets. Three FCCs were tested to provide a sampling of different HQ (and thus different PIORs). Two HUD targets were tested: the high-fidelity tracking task, designed to mimic the motion of an actual aircraft; and the low-fidelity tracking task obtained from MIL-STD-1797A (Reference 1).

Test Procedures

Each pilot flew phase 1 and 2 maneuvers for all combinations of the three FCCs and tracking tasks. Phase 1 maneuvers consisted of gentle maneuvering and capture tasks designed to judge aircraft susceptibility to exceeding limits or causing VSS safety trips during phase 2 maneuvering. Phase 2 maneuvering was the specialized HQDT technique. See Appendix G for a complete description. The FCCs were baseline, increased stick sensitivity, and increased time delay. The tracking tasks were against an actual aircraft target, high-fidelity HUD target, and low-fidelity HUD target.

All data points were accomplished at the same test conditions (0.75 Mach at 15,000 feet PA). To isolate the task to the pitch axis, the throttle was controlled by the safety pilot to remove airspeed and closure from the evaluation. In addition, the evaluation pilot was instructed to only correct pitch tracking errors and ignore minor lateral pipper errors. Following each phase 2 maneuver a PIOR was assigned. Each pilot successfully accomplished the maneuvers listed in the procedure section above.

Test Results

The results (sorted by FCC) are presented in Figures 9, 10, and 11. It was necessary to compare groups of PIORs and CHRs. When there was more than one set of data from which to generate ratings (most situations), rather than show every rating, which numbered in excess of 10 in several cases, an average rating is shown. In each case where multiple ratings are presented, the error bars shown in the figures denote the maximum and minimum ratings given. The error bars are not statistical in nature. For every maneuver presented, the detailed data can be found in Appendix E.

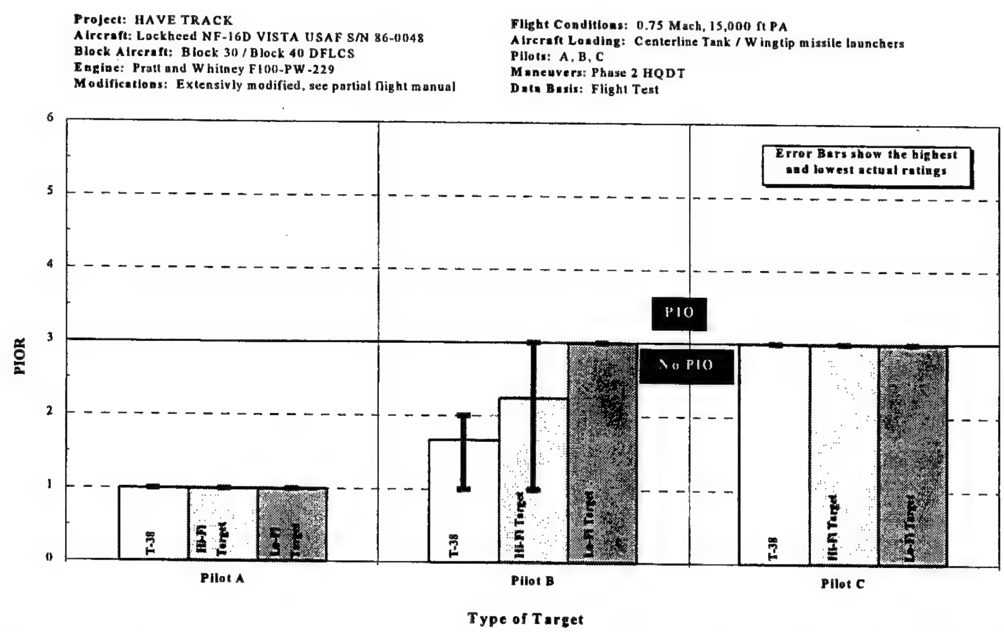


Figure 9 Comparison of Pilot-Induced Oscillation Ratings (PIORs): Three Tracking Tasks, Handling Qualities During Tracking, and Baseline Flight Control Configuration

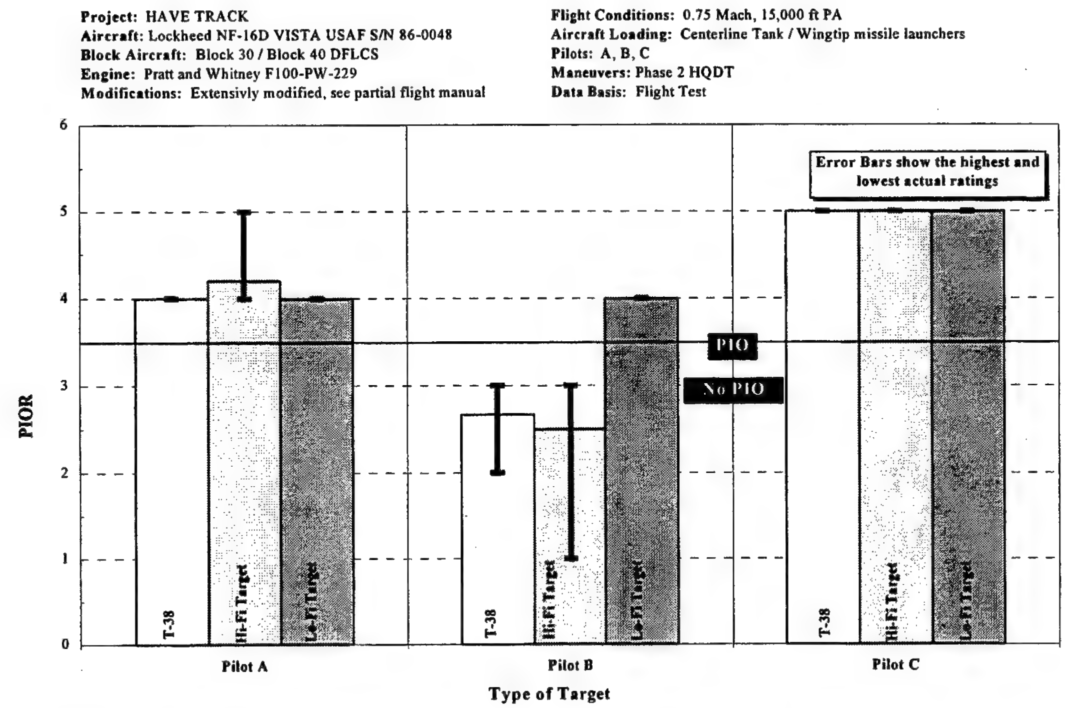


Figure 10 Comparison of Pilot-Induced Oscillation Ratings (PIORs): Three Tracking Tasks, Handling Qualities During Tracking, and Sensitive Stick Flight Control Configuration

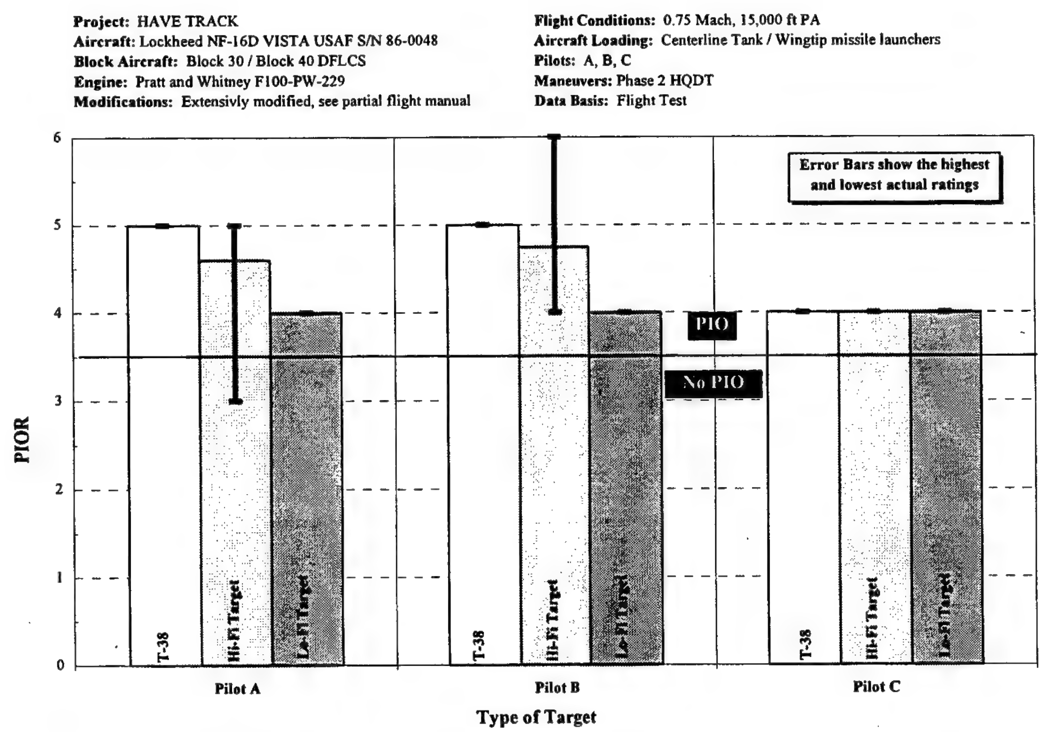


Figure 11 Comparison of Pilot-Induced Oscillation Ratings (PIORs): Three Tracking Tasks, Handling Qualities During Tracking, and Added Time Delay Flight Control Configuration

In order to demonstrate that each of the HUD tracking tasks was as useful as an actual aircraft tracking task for predicting PIO, the PIORs obtained using each of the HUD tasks should correlate with the results obtained using an actual aircraft target for each FCC tested. For the baseline configuration (Figure 9) two of the three pilots showed exact correlation between the three targets. One pilot had varied PIORs from 1 to 3 for the three targets. Correlation was the same for the sensitive stick case, with two pilots showing similar ratings across the targets and one pilot (the same pilot as before) varying PIORs from 1 to 4 (Figure 10). The time delay configuration showed less correlation across the board (Figure 11). The PIORs varied from 3 to 5, 4 to 6 and 4 for each of the pilots, respectively. The PIOR of 6 was given when the pilot unconsciously induced an oscillation prior to the start of HQDT. Variation between the pilots was attributed to the different backgrounds of the pilots. This is discussed further under MOP 1.2.

Additional insight can be gained by comparing the PIORs across the FCCs. The baseline configuration was rated as a PIO of 3 or better using all three targets by all three pilots. The sensitive stick configuration was rated as a PIO of 4 or worse by two of the pilots using all three targets. The third pilot showed good correlation between the T-38 aircraft and high-fidelity HUD task with PIORs of 3 or better, but rated the low-fidelity task a PIO of 4. Differences between pilots were again noted and attributed to differing pilot backgrounds. The time delay was, however, consistently rated 4 or worse using all three targets.

The HUD tasks, combined with the HQDT, were successful in predicting PIO susceptibility. The correlation from configuration to configuration showed that the HUD targets resulted in the same characterization of PIO as the actual target, either prone (PIOR 4 or worse) or not prone (PIOR of 3 or better) in all but 2 of the 18 comparisons.

Throughout the phase 2 testing, two areas of difficulty were noted. The first difficulty was the attempt to isolate the pitch axis during the tracking tasks. The throttle was controlled by the safety pilot to remove airspeed and closure from the evaluation. The evaluation pilot attempted to track pitch errors only and ignore minor lateral pipper errors. Pilots commented that "large lateral excursions both left and right resulted in less than adequate performance," "performance was directly related to how well and how quickly I was able to stabilize on the target's bank angle," and "workload was moderate to high and was driven by lateral control difficulties more than pitch difficulties."

For the configurations tested, the lateral motions of the pipper were large enough that they affected task performance and could not simply be ignored in flight. This was quite apparent during HQDT. While the evaluation pilot corrected gross lateral errors, performance of the HQDT task suffered. This difficulty in decoupling the axes during tracking applied to both the actual aircraft tracking tasks and the HUD tracking tasks and therefore had minimal effect on the test results.

The second area of difficulty noted throughout the phase 2 testing was differing HQDT techniques between the pilots. While an attempt was made to standardize the HQDT technique (Appendix G), postflight evaluation of HUD tracking task error signals and pilot stick inputs showed that each pilot had a slightly different HQDT technique. **To standardize HQDT techniques, train test pilots using an aircraft or simulator that can display tracking error time traces relative to pilot stick inputs. (R1)**[1]

The HQDT technique attempted to force a pilot into a high bandwidth control technique while reducing the level of pilot compensation. One pilot developed an HQDT technique involving a constant amplitude step input control with stick reversals applied at zero error. The pilot's time delay was the only control parameter that coupled with the aircraft flight controls.

A second pilot developed a technique of sizing the control input based on the error. The pilot still performed stick reversals at zero error. This proportional amplitude HQDT allowed the pilot to compensate based on the perceived error rate (pitch rate in this case) when zero error was observed. Examples of these HQDT techniques are presented in Appendix G. The HUD-generated targets and error signals provided extremely useful feedback in standardizing the pilots' HQDT techniques.

Differing pilot HQDT techniques would not have been discovered without the aid of the HUD tracking tasks and the associated tracking task error signals.

[1]Numerals preceded by an R within parentheses at the end of a paragraph correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

The utility of several HQDT techniques was examined. All techniques stipulated stick force reversal no earlier than error signal reversal. A constant amplitude step input technique was examined first with small amplitude inputs. A second technique was identical only with large step inputs. These techniques were easy to standardize, but it was difficult for the pilot to assess PIO susceptibility. The aircraft would always oscillate, either following a pilot's input, out of phase with the pilot but bounded, or out of phase with the pilot and unbounded.

The last technique was the proportional amplitude step inputs. The pilot sized the amplitude based on the perceived error rate as the error passed through zero. Convergent oscillations were observed with this technique, as well as the previously described bounded and growing oscillations. This technique allowed the pilot to better assess PIO susceptibility. Pilots commented that using proportional amplitude "in the time delay case, as the amplitude of the input was increased, the overshoots got larger and eventually the oscillation diverged," "baseline configuration showed very little tendency to diverge in the proportional input HQDT," and "the proportional amplitude HQDT gave me a better feeling for the PIO susceptibility of the jet." Although not conclusive, the statements suggest that the best technique to wring out the PIO susceptibility of a new aircraft was the proportional technique.

The best HQDT technique for consistently classifying the PIO susceptibility of an aircraft was the proportional amplitude technique, reversing at zero error, with as close to a step input as possible. **Accomplish additional testing to quantify the advantages of proportional amplitude HQDT technique for identifying PIO susceptibility. (R2)**

MOP 1.2 – Pilot Ratings During Operationally Representative Tracking.

This MOP compared the CHRs and PIORs obtained during phase 3 tracking of an actual air-to-air target aircraft to the CHRs and PIORs obtained during phase 3 tracking of HUD-generated virtual targets. Three FCCs were tested to provide a spread of different HQ (and thus different CHRs and PIORs). Two HUD targets were tested: the high-fidelity tracking task, designed to mimic the motion of an actual aircraft and the low-fidelity tracking task obtained from MIL-STD-1797A (Reference 1).

Test Procedures

Each pilot flew multiple phase 3 maneuvers for all combinations of the FCCs: baseline, increased stick sensitivity, and added time delay; and the tracking tasks: actual aircraft target, high-fidelity HUD target, and low-fidelity HUD target. All data points were accomplished at the same test conditions (0.75 Mach at 15,000 feet PA). A description of the phase 3 maneuver follows:

Phase 3: The pilot tracked the target in an 'operational' manner attempting to maximize the time the pipper spent on the target. During the maneuver the safety pilot controlled the throttle to maintain maneuver tolerances with the goal of minimizing closure rates when tracking the actual target and keeping the task consistent when tracking HUD generated targets. Following each phase 3 maneuver a PIOR and a CHR were given.

Table 2 lists tracking task performance criteria for each tracking task.

Table 2
TRACKING TASK PERFORMANCE CRITERIA

Target Used	Desired Performance	Adequate Performance
Actual and High-Fidelity Targets	Target center[1] kept within 5-mil[2] circle of HUD reticle for 50 percent of tracking time.	Target center kept within 10-mil circle of HUD reticle for 50 percent of tracking time.
Low-Fidelity Target	Target center kept within 10-mil circle of HUD reticle for 50 percent of tracking time.	Target center kept within 25-mil circle of HUD reticle for 50 percent of tracking time.

[1]Target center on the T-38 was the intersection of the trailing edge of the wing and the centerline of the fuselage.
[2]mil - milliradian

Test Results

Comparisons of the PIORs assigned after phase 3 maneuvers, sorted by FCC, are presented in Figures 12, 13, and 14. The comparison of CHRs, sorted by FCC, are presented in Figures 15, 16, and 17. Expected results were a match of the PIORs between the T-38 target and the HUD targets for each specific FCC. For the baseline configuration, PIORs were all 3 or better regardless of the target. For the baseline configuration, the HUD targets correlated well against the T-38 target for predicting a non-PIO prone FCC. The correlation between the HUD targets and the T-38 target with the sensitive stick configuration was also good. One pilot rated consistently PIO prone (4 or worse). Another rated consistently not PIO prone (3 or better). The last pilot rated PIORs of 3 and 4. There was consistency in that the pilot rated both 3 and 4 while flying against the T-38 target and against the high-fidelity HUD target. So for the baseline and the sensitive stick configurations, the HUD targets result in the same PIORs as the T-38 target.

This result does not bear out in the time delay case. The HUD targets typically resulted in worse PIORs than the T-38 target. The first pilot was consistent between the T-38 and HUD targets. The second pilot had some learning effects using the high-fidelity target. The third pilot rated the FCC as PIO prone when using the HUD targets when the T-38 target was rated a 3.

Phase 3 tasks and HUD-generated targets may or may not be useful in determining PIORs. There was weak correlation for the baseline and sensitive stick cases and none for the time delay case. The results were indeterminate.

The ability of HUD target tracking to generate CHRs in line with actual aircraft tracking were evaluated. Expected results were a match of the CHRs between the T-38 target and the HUD targets for each specific FCC. For the baseline configuration (Figure 15) the CHRs ranged from 3 to 6 against the T-38 target. Desired performance was always achieved with the low-fidelity task and this was reflected in the assigned CHRs that ranged from 2 to 4. The high-fidelity task resulted in CHRs ranging from 5 to 7. These differences, to a certain extent, were driven by the task performance criteria. Each pilot commented that the task performance criteria was too easy for the low-fidelity task and too hard for the high-fidelity task; this issue is further addressed under objective 2. The high-fidelity target resulted in CHRs equal to or worse than the T-38 CHRs and the low-fidelity target resulted in CHRs equal to or better than the T-38 target.

For the sensitive stick configuration (Figure 16) the CHRs ranged from 3 to 6 for the T-38 target, 3 to 5 for the low-fidelity target, and 5 to 8 for the high-fidelity target. There was slightly better correlation between the low-fidelity task and the T-38 target than the high-fidelity task and the T-38 target. But this correlation was tenuous at best. The high-fidelity target again resulted in CHRs equal to or worse than the T-38 CHRs, and the low-fidelity target resulted in CHRs equal to or better than the T-38 target.

For the time delay configuration (Figure 17) the CHRs ranged from 5 to 8 for the T-38 target, 4 to 5 for the low-fidelity target, and 5 to 10 for the high-fidelity target. There was no strong correlation between the targets. The scatter in the CHRs may have been driven by the task performance criteria being too loose or too tight.

Phase 3 tasks and HUD generated targets may or may not be useful in determining CHRs. The results were indeterminate.

Scatter in the CHRs may have also resulted from the lack of fidelity in the HUD targets. Pilot comments indicated the high-fidelity HUD task did not model the T-38 target's reversal well. It was observed that the T-38 target was easier to track through the reversal than the high-fidelity target, partially because the T-38 target rolled slower than the high-fidelity HUD target. One pilot noted "the design of the high-fidelity task was not realistic. Specifically, g onset rates were too fast." A higher-fidelity HUD target model would have more closely matched roll rates and g onset rates. The high-fidelity task was not high enough in fidelity to match CHRs between the actual aircraft tracking and HUD target tracking. **Accomplish additional testing on a more accurate, higher fidelity, HUD target model. (R3)**

MOP 1.3 – Effective Time Delay in the VISTA Flight Test HUD.

This MOP characterized the amount of time delay in the VISTA flight test HUD. A complete

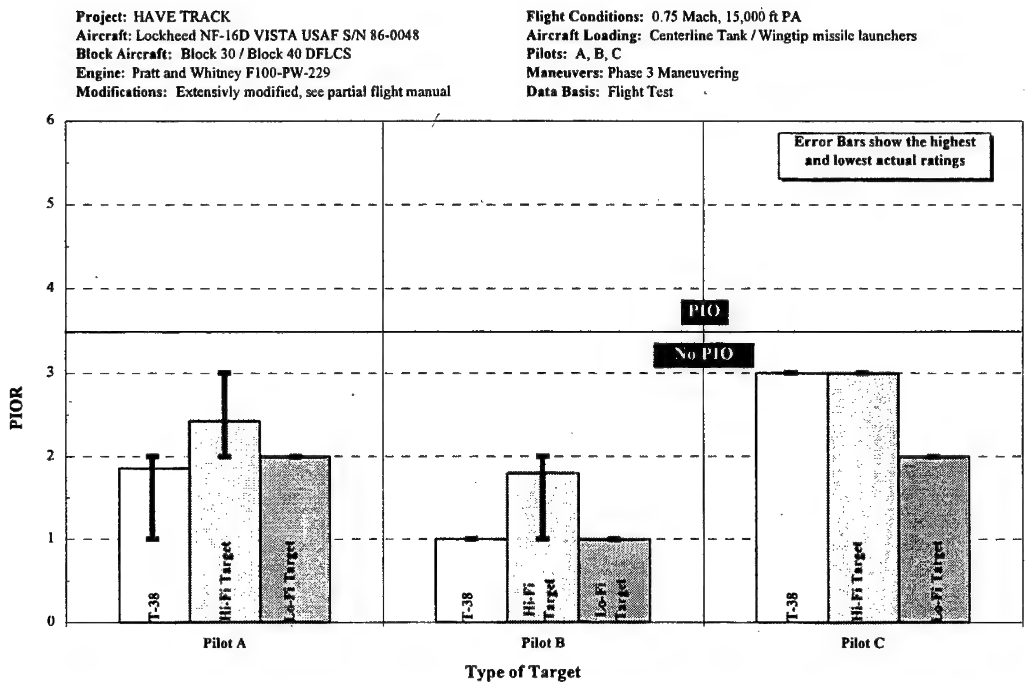


Figure 12 Comparison of Pilot-Induced Oscillation Ratings (PIORs): Three Tracking Tasks, Baseline Flight Control Configuration

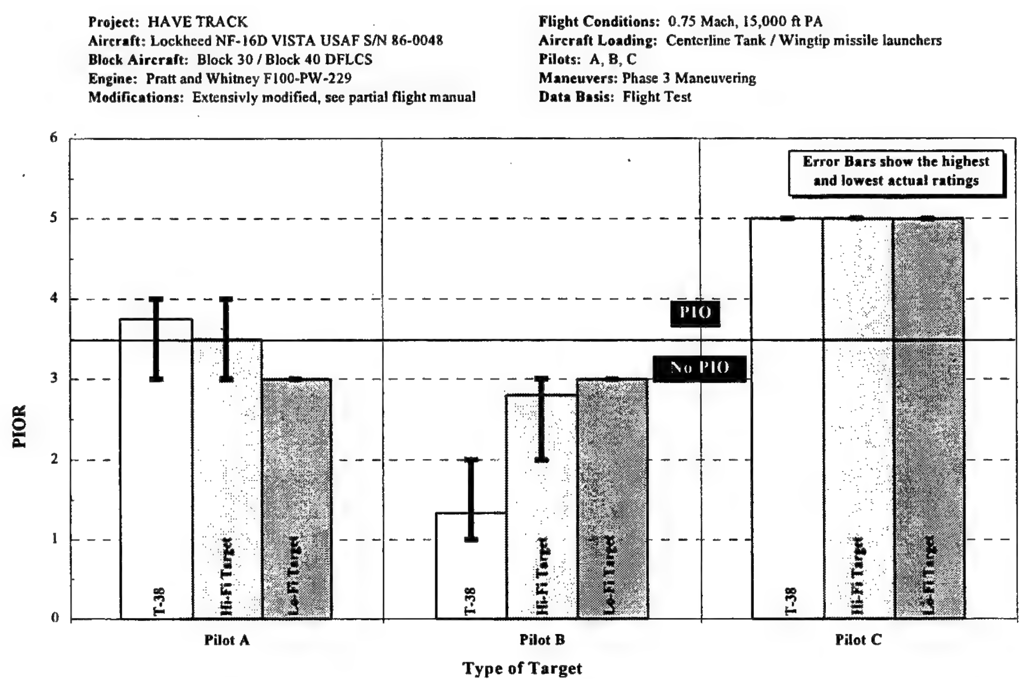


Figure 13 Comparison of Pilot-Induced Oscillation Ratings (PIORs): Three Tracking Tasks, Sensitive Stick Flight Control Configuration

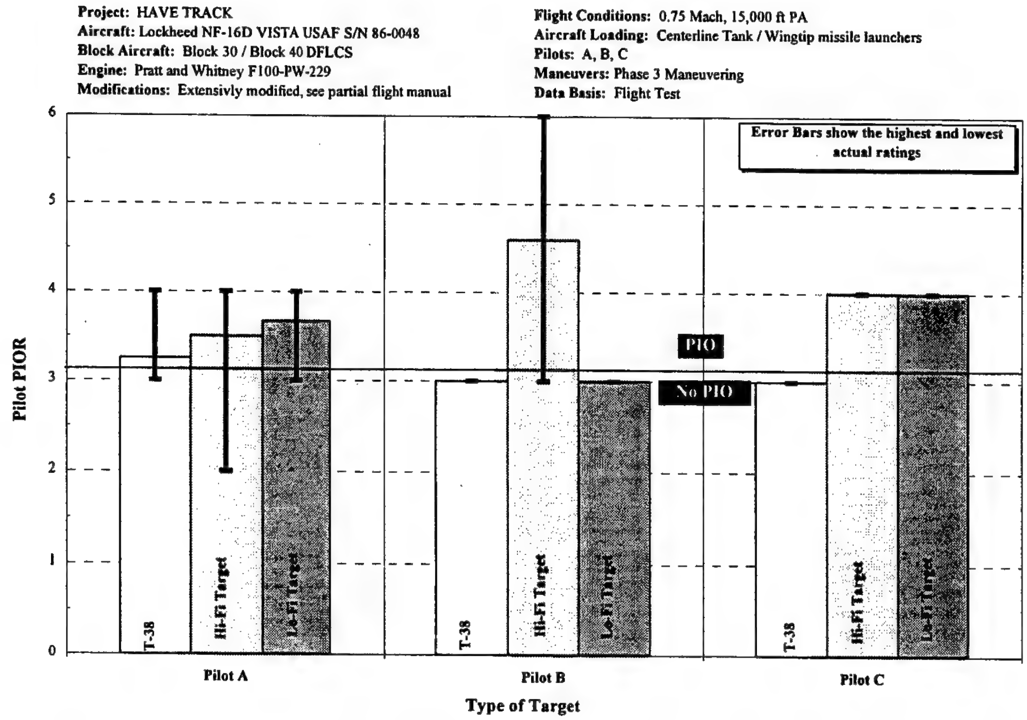


Figure 14 Comparison of Pilot-Induced Oscillation Ratings (PIORs): Three Tracking Tasks, Added Time Delay Flight Control Configuration

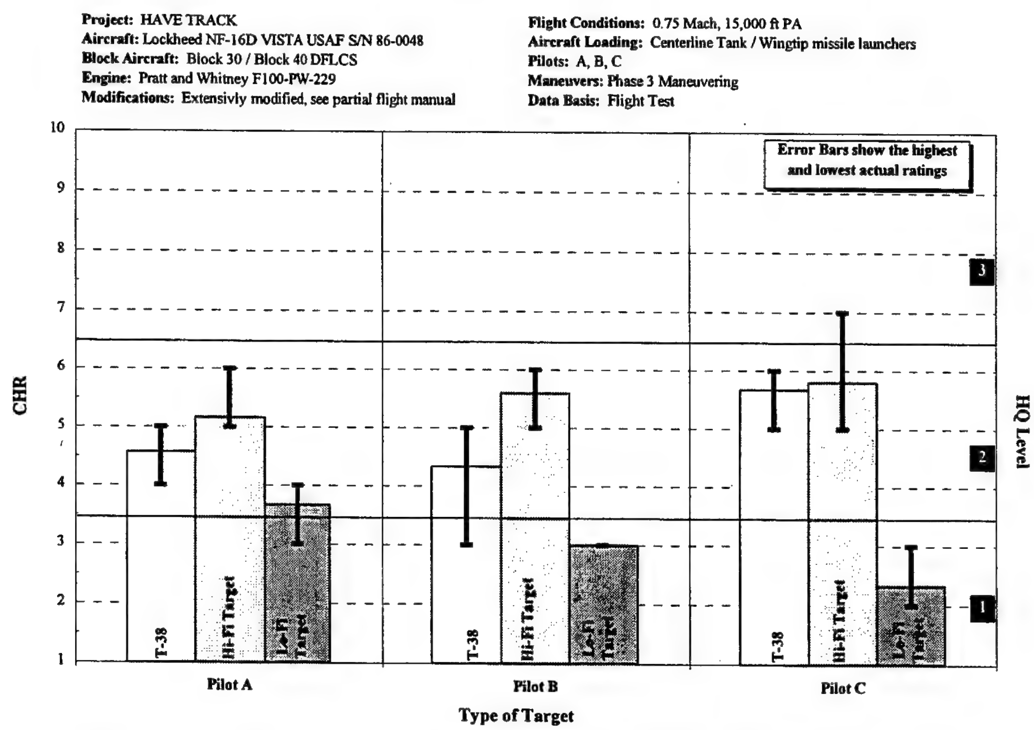


Figure 15 Comparison of Cooper-Harper Ratings (CHRs): Three Tracking Tasks, Baseline Flight Control Configuration

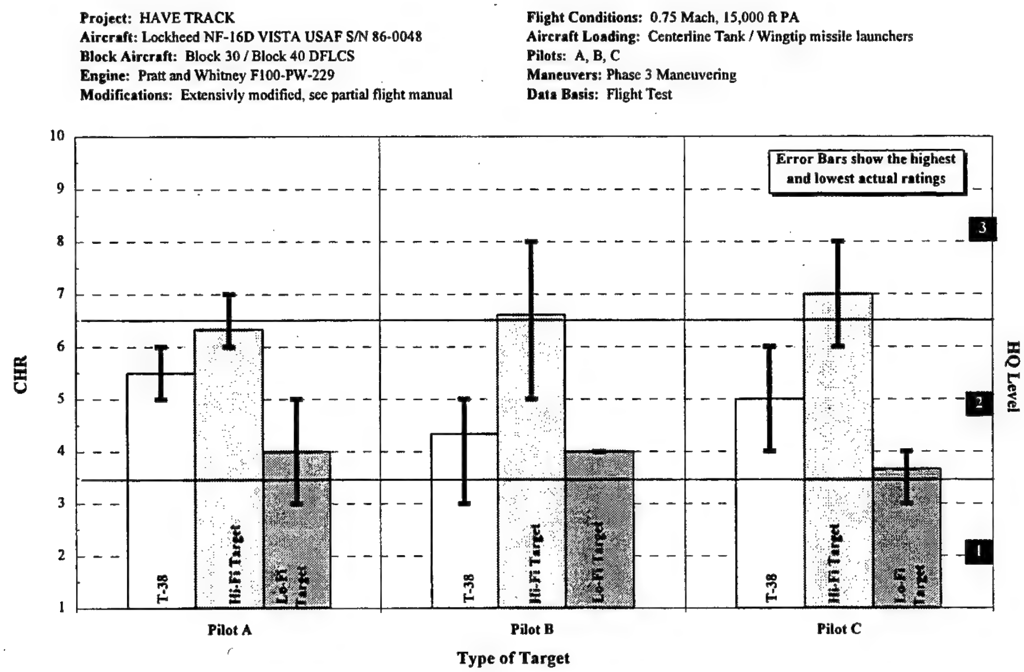


Figure 16 Comparison of Cooper-Harper Ratings (CHRs): Three Tracking Tasks, Sensitive Stick Flight Control Configuration

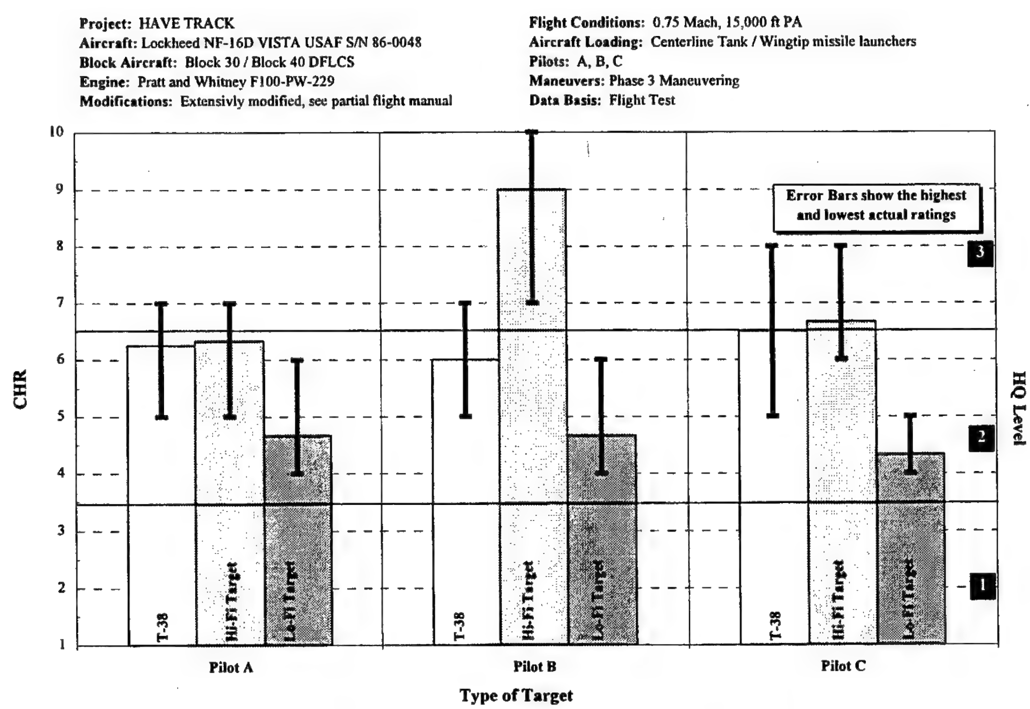


Figure 17 Comparison of Cooper-Harper Ratings (CHRs): Three Tracking Tasks, Added Time Delay Flight Control Configuration

characterization of the time delay contained in the HUD and instrumentation system of the F-16 VISTA aircraft was beyond the scope of this project. None of the pilots commented on unusual amounts of time delay.

Test Procedures

In order to determine a bound for the time delay associated with the F-16 VISTA programmable flight test HUD, aileron rolls were performed in the aircraft. During the rolls, the pilot commented on the amount of bank error between the horizon line in the flight test HUD and the actual horizon. Table E2 (Appendix E) shows the results of these maneuvers.

Test Results

The time delay of the F-16 VISTA flight test HUD was estimated as between 20 and 40 milliseconds, but not measured directly. The accuracy of the timestamps associated with the instrumentation parameters were not fully evaluated. This evaluation was beyond the budget of the project.

Objective 2: Evaluate Numerical Methods as a Backup for Pilot Ratings:

Objective 2 was met. The purpose of Objective 2 was to evaluate the use of numerical methods for predicting aircraft HQ.

There were two MOPs for Objective 2: numerical methods for PIORs, and numerical methods for handling qualities ratings (HQRs).

A limitation of the R. Smith criteria when using time-history data from an actual flight test is it cannot determine PIO susceptibility in cases where stick sensitivity is the cause. In these cases, the R. Smith criteria rated the PIO susceptibility of the sensitive stick FCC the same as the baseline FCC. The R. Smith program can however make assessments of PIO susceptibility for configurations with added time delay. Results for the sensitive stick FCC are presented with the results for the baseline and added time delay FCCs but are not discussed in detail.

MOP 2.1 – Numerical Methods for PIORs.

The objective of this MOP was to evaluate the use of the R. Smith criteria for predicting aircraft PIO susceptibility from the open-loop frequency response data for each aircraft FCC.

Test Procedures

Each pilot completed a pitch frequency sweep in each FCC. This was accomplished by first stabilizing the appropriately configured aircraft at the test condition (0.75 Mach at 15,000 feet PA) and then trimming the aircraft to maintain a level, 3.0-g turn. Once stabilized in the 3.0-g turn, the pilot accomplished the sinusoidal frequency sweep, using the trimmed 3.0-g condition as a neutral point, ensuring a minimum of 30 seconds of data. The data generated during these maneuvers were used as input data for the R. Smith computer software program, which applied the R. Smith criteria to predict PIO susceptibility for each FCC. Table C1 (Appendix C) provides a complete list of recorded parameters. Pilot ratings used as a basis for comparison were those obtained as part of MOP 1.1.

Test Results

Figure 18 compares the analytical results based on data gathered while tracking the T-38 target during the two different test maneuvers (HQDT and phase 3 tracking) for each of the FCCs. Similar charts showing the results obtained while tracking the high- and low-fidelity HUD targets are presented in Figures F1 and F2 (Appendix F).

Figure 18 shows the PIORs predicted by the R. Smith criteria using data generated from three different types of maneuvers. As previously described, for multiple ratings, rather than show every rating, which numbered in excess of 10 in several cases, an average rating is presented. Error bars denote the maximum and minimum predicted ratings and are not statistical in nature. When only one rating was available, no error bars are shown. Complete, detailed data are presented in Appendix E. Comparing the three FCCs in Figure 18, predicted ratings are fairly consistent using data from all three types of maneuvers. Ratings predicted from

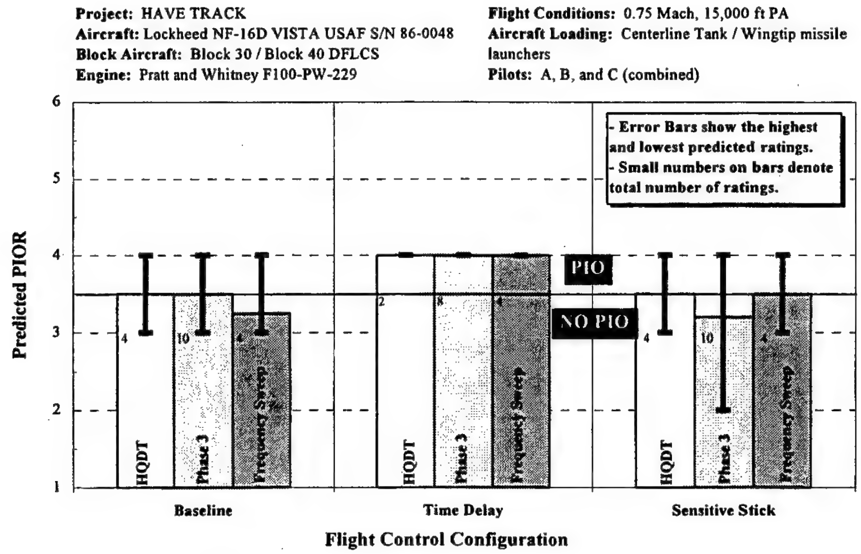


Figure 18 Comparison of Predicted Pilot-Induced Oscillation Ratings (PIORs) From the R. Smith Criteria

data generated by phase 3 maneuvers are the least consistent, while ratings from data generated by HQDT and frequency sweeps are nearly identical. The R. Smith critera uses frequency response estimation methods to predict PIORs and HQRs. Data obtained using HQDT did not always contain enough frequency content to predict a PIOR. However, the program could assign ratings for every set of frequency sweep data. Therefore, R. Smith predictions were based on data generated from frequency sweeps for the remainder of this evaluation.

Figures 19 and 20 show PIORs given by each pilot for each combination of FCC and target compared to PIORs predicted by the R. Smith criteria. Figure 19 compares PIORs given during HQDT and Figure 20 compares PIORs given during phase 3 tracking maneuvers. Fewer HQDT maneuvers were flown than phase 3 maneuvers and in most cases only one HQDT maneuver was flown by each pilot for each FCC/target combination. Appendix G presents time traces of pilot inputs during HQDT and further discussion on exactly how HQDT maneuvers were flown.

When PIORs were given during HQDT, an interpretation problem was encountered with the PIOR scale used (Appendix B). For HQDT, there was not a defined "task" with associated performance criteria, only "aggressive and assiduous tracking of a precision aimpoint" always driving any perceptible tracking error to zero. All pilots agreed on the scale's definition of ratings of 4, 5, and 6, which are clear from the flow chart in Appendix B. The problem arose with ratings of 1, 2, and 3. A rating of 2 or 3 means the pilot initiated abrupt maneuvers or tight control which did not cause oscillations (PIO). The PIO scale then asks if undesirable motions occur, and if so, if task performance was compromised. When there is no defined task, this question cannot be answered without ambiguity. The pilots interpreted this ambiguity differently. If there was no PIO tendency, Pilot A rated the aircraft a 1 due to the lack of a defined task. Pilot C assigned ratings of "3 or less," also because of lack of a defined task. Pilot B attempted to characterize subtleties in the flight control system as undesirable motions and gave ratings of 1, 2, and 3. All three pilots were in agreement about the PIO susceptibility of the FCC (PIO or no PIO), but they were not uniform in how they interpreted ratings of 1 through 3. For evaluation purposes, any rating of 3 or less based on an HQDT maneuver was considered equivalent.

When PIORs were given during HQDT, an interpretation problem was encountered with the PIOR scale used (Appendix B). For HQDT, there is not a defined "task" with associated performance criteria, only "aggressive and assiduous tracking of a precision aimpoint" always driving any perceptible tracking error to zero. All pilots agreed on the scale's definition to ratings of 4, 5, and 6, which are clear from the flow chart in Appendix B. The problem arose with ratings of 1, 2 and 3. A rating of 2 or 3 means the "pilot initiated abrupt maneuvers or tight control" which did not cause oscillations, a.k.a. PIO. The PIO scale then asks if undesirable motions occur, and if so, if task performance was compromised.

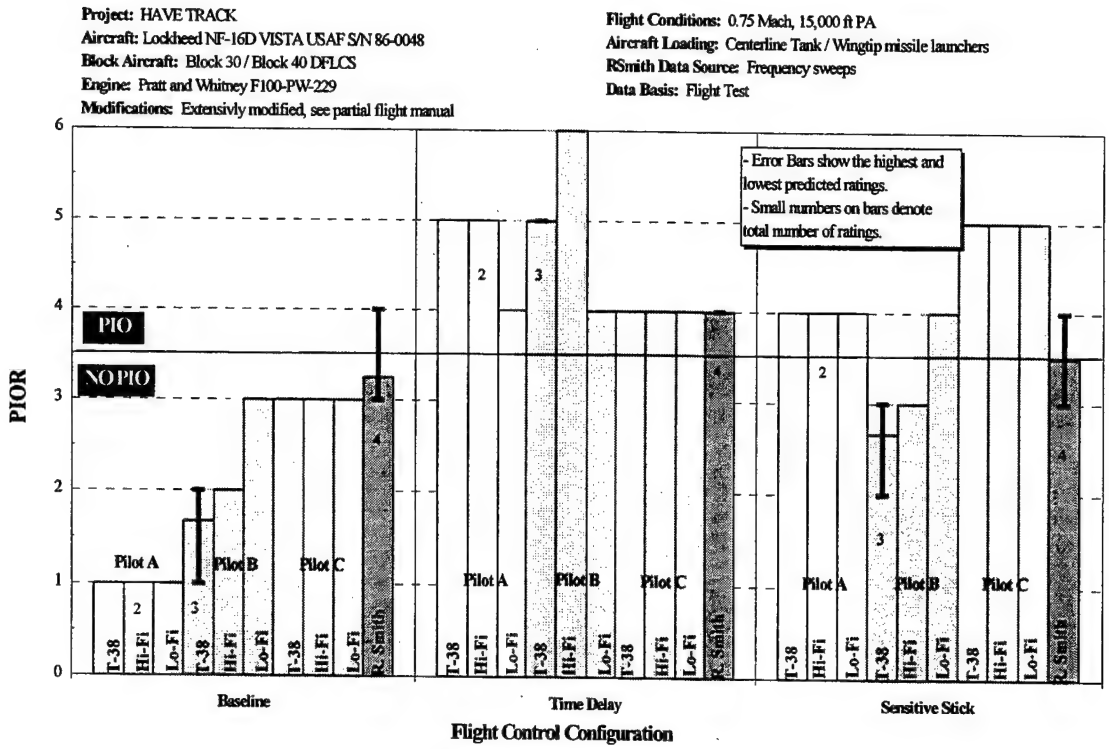


Figure 19 Comparison of Pilot-Induced Oscillation Ratings (PIORs) Using Handling Qualities During Tracking and Different Targets

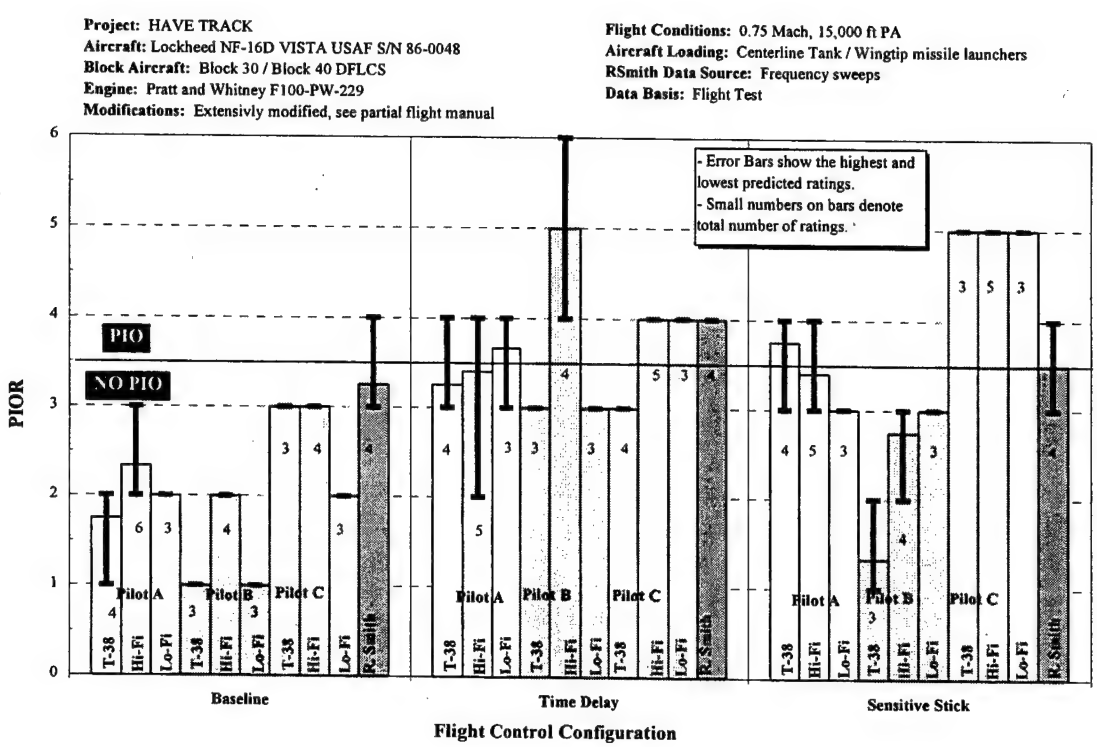


Figure 20 Comparison of Pilot-Induced Oscillation Ratings (PIORs) From Phase 3 Maneuvers versus Different Targets

When there was no defined task, this question could not be answered without ambiguity. The pilots interpreted this ambiguity differently. If there was no PIO tendency, Pilot A rated the aircraft a 1 due to the lack of a defined task. Pilot C assigned ratings of "3 or less," also because of lack of a defined task. Pilot B attempted to characterize subtleties in the flight control system as undesirable motions and gave ratings of 1, 2, and 3. All three pilots were in agreement about the PIO susceptibility of the FCC (PIO or no PIO), but they were not uniform in how they interpreted ratings of 1 through 3. For evaluation purposes, any rating of 3 or less based on an HQDT maneuver was considered equivalent. The 1 through 6 PIO scale, Figure B2 (Appendix B), has ambiguities that make it inappropriate for use with the HQDT maneuver. **Develop a specific rating scale for use with HQDT that allows ratings of: not PIO prone; PIO prone with bounded oscillations; or PIO prone with divergent oscillations. (R4)**

Using this adjusted PIO scale criterion, R. Smith predictions for the baseline FCC (Figure 19) correlated well with pilot ratings (rating of 3 or less). For the time delay configuration, R. Smith predictions also correlated well with pilot ratings, being within 1 rating scale value for 11 out of 12 pilot ratings.

Figure 20 shows the effects of giving PIORs during an actual operational tracking task with defined performance criteria (phase 3 maneuvers). For the baseline configuration, pilots easily characterized subtleties in the flight control system and ratings of 2 and 3 became meaningful. For phase 3 maneuvers, however, R. Smith predictions only correlated with each pilot's *worst* ratings for each FCC.

For the time delay configuration, R. Smith predictions also only agreed with the worst pilot ratings given, but, in this case, the pilots did not agree with each other. During some tracking tasks, the pilots experienced PIO (in some cases severe PIO) while in others they only noticed undesirable motions. This demonstrates a limitation of using phase 3 tracking to identify PIO susceptibility.

As previously discussed, a limitation of the R. Smith criteria is its inability to predict PIO when stick sensitivity is the cause. As can be seen from Figure 19, an over sensitive control stick can be a major source of PIO and during this evaluation, 11 out of 12 times, pilots found the sensitive stick configuration to be PIO prone.

Except in cases where stick sensitivity was the source of PIO, predictions from the R. Smith criteria correlated well with pilot ratings following HQDT maneuvers as PIO prone or not. R. Smith predictions tended to be conservative (worse than pilot ratings) for phase 3 tracking tasks, but not in all cases. The R. Smith program was therefore a satisfactory predictor of PIO susceptibility from aircraft open-loop frequency response.

While there was difficulty in using the 6-level PIO scale for rating HQDT maneuvers, the scale worked well for phase 3 tracking tasks. The 6 levels allowed characterization of the flight control system with and without encountering PIO. As previously described a significant limitation of rating the PIO susceptibility of an aircraft during phase 3 tracking tasks is that PIO might be missed. When tracking a target within an "acceptable" error tolerance, rather than always trying to achieve exactly zero error (HQDT), most pilots adopt a technique of lowering their bandwidth or "gain" to improve performance. When this occurs, the frequency content of their control inputs varies and may or may not excite PIO. This is illustrated in Figure 20, especially in the time delay configuration, where pilot ratings varied significantly. The R. Smith program did not predict this, and only gave ratings of 3 (not PIO prone) or 4 (PIO prone). Phase 3 tracking tasks should not be relied upon for assessing PIO susceptibility because pilot bandwidth may not be sufficient to excite PIO during such tasks.

MOP 2.2 – Numerical Methods for Handling Qualities Ratings.

The objective of this MOP was to evaluate the use of numerical methods for predicting pilot ratings of aircraft HQ.

Pilot ratings for each combination of the three aircraft FCCs and the two HUD tracking tasks obtained in MOP 1.2 were compared to:

1. Cooper-Harper ratings predicted by the R. Smith criteria.

2. Cooper-Harper ratings generated using the HUD error signal for determining task performance and the pilot bandwidth obtained from the PSD of pilot stick force inputs to determine pilot physical workload.

Test Procedures

The data listed in Appendix C was recorded during each maneuver flown as part of objective 1. This included all combinations of pilot, FCC, and target type. The frequency sweep data collected as part of MOP 2.1 was also used. Each phase 3 tracking task or frequency sweep was used as a separate input for the R. Smith software, which applied the R. Smith criteria, Reference 4, to predict pilot ratings (Cooper-Harper scale) for each FCC. These ratings were then compared to the pilot ratings obtained during the data collection for MOP 1.2.

In addition to the standard method of applying the R. Smith criteria via the θ/F_s transfer function, the R. Smith program offered a second method of application using the HUD error signal (described below) via the Error/F_s transfer function. This alternate method was only useful for HUD tracking task data and was evaluated in addition to the standard method in these cases.

For the second method of predicting pilot ratings, pilot performance and workload were measured to predict CHRs. For performance, the data recorded during each HUD tracking task was used to determine the distance between the HUD-generated target and the center of the fixed reticle (pipper). This was referred to as the HUD error signal. The error was initially in the form of X error (horizontal) and Y error (vertical). The MATLAB® computer software program was used to generate HUD error time histories by plotting the root mean square (RMS) of the X and Y error signals and to measure the percentages of time the distance was less than 5, 10, and 25 mils. The results were then compared to the established tracking criteria (see Table 2) to determine whether desired or adequate performance was attained for that particular task.

To quantify pilot workload, MATLAB® was used to produce power spectral density (PSD) plots from the data recorded from each HUD tracking task for each pilot, FCC, tracking task, and target type. The pilot's bandwidth for each task was determined by reading the frequency of the PSD at one order of magnitude lower than the value at the peak of the PSD. Workload was estimated by comparing the pilot's bandwidth during each phase 3 tracking task to his bandwidth during HQDT for the same target and FCC. Workload during HQDT was used as the measure of maximum attainable workload. Relative bandwidth changes were then used to predict perceived changes in pilot workload.

Test Results

Figure 21 shows predicted pilot ratings (Cooper-Harper scale) from the R. Smith program based on data obtained when the pilots tracked each type of target in each FCC. Figure 21 also shows the R. Smith predictions using data from frequency sweeps. The alternate method of applying the R. Smith criteria via HUD error signals was not used in the analysis (see Appendix E for a comparison of predictions from the two different methods). Data were presented in the same manner as in MOP 2.1: where more than one rating for the same task was computed, the average rating is shown with error bars denoting absolute maximum and minimum predicted values (see Appendix E for detailed data.)

The results obtained for R. Smith program predictions of aircraft HQRs were very similar to those found for the predicted PIORs in MOP 2.1. The R. Smith program gave the most consistent results and the highest level of confidence when using data obtained from frequency sweeps. The R. Smith criteria for flight test data were based on frequency response analysis; therefore, maneuvers which provided data over a wide range of frequencies resulted in the most consistent results. Although the data recorded during tracking tasks gave similar results, it tended to have less frequency content than the frequency sweeps did, and resulted in a wider spread of HQRs. This can readily be seen in Figure 21. Therefore, throughout this MOP, all R. Smith predictions used for comparison were based on frequency sweep data.

The R. Smith program was also run using time-history data of the HUD error signal for evaluation purposes. In general, the ratings given when using the HUD error signal were less consistent (more scatter), and were 1 to 2 ratings higher than those given when using the pitch rate/stick force data. Additionally, this method could only be used for HUD tracking tasks. Therefore, the standard method of applying the R. Smith criteria via the θ/F_s transfer function was used for this MOP. Figure F3 (Appendix F) shows a comparison of the two methods of applying the R. Smith criteria.

Frequency sweeps provided the most consistent data for the R. Smith program to predict aircraft HQRs. Figure 22 shows a comparison of actual pilot

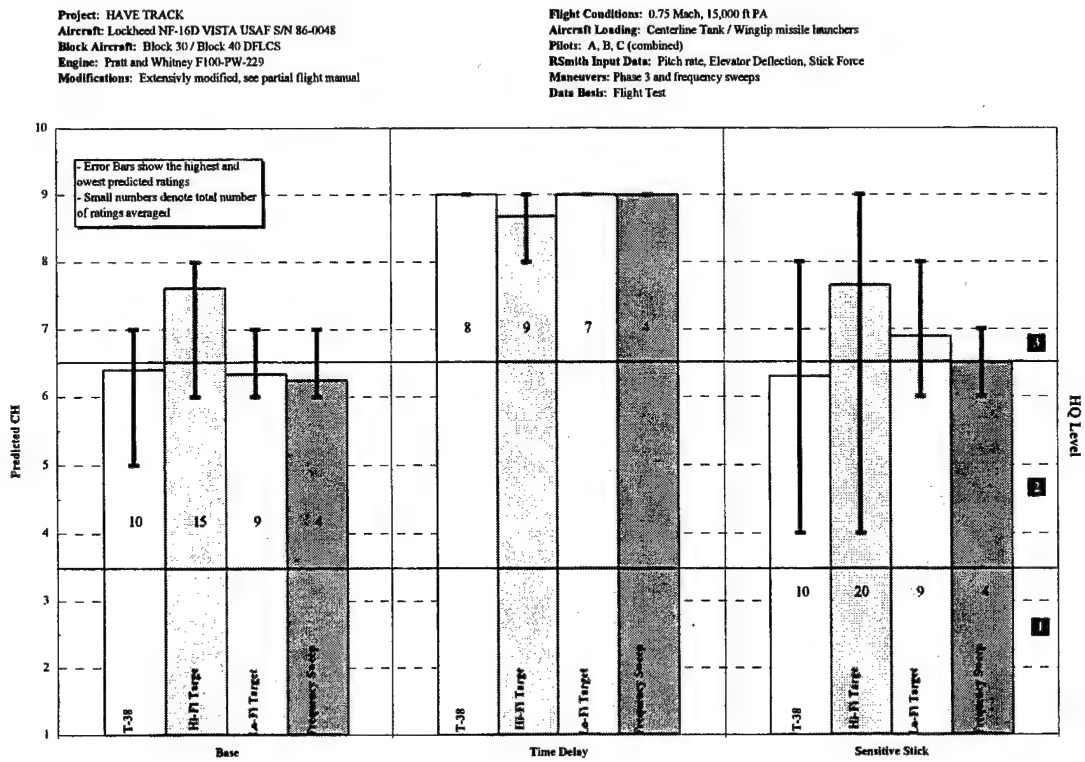


Figure 21 Comparison of Cooper-Harper Ratings (CHRs) Obtained From the R. Smith Program

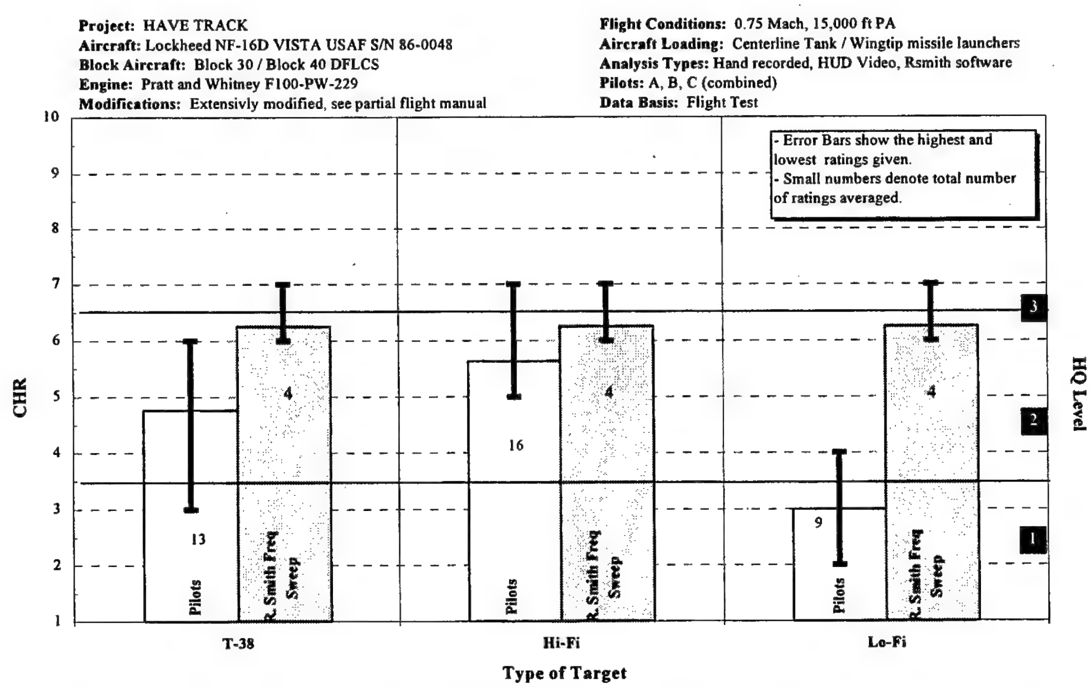


Figure 22 Comparison of Cooper-Harper Ratings (CHRs) and R. Smith Criteria Predictions, Baseline Flight Control Configuration

ratings to R. Smith program predictions for the baseline FCC. Pilot ratings were given after tracking each of the three different types of targets. The same comparisons for the added time delay configuration and the sensitive stick configuration can be found in Figures F4 and F5 (Appendix F).

Using the T-38 tracking task as the 'truth source,' these figures show the R. Smith criteria tended to be conservative (worse ratings than pilots). Overall, the R. Smith predictions were 1 to 3 ratings worse than those given by pilots after the T-38 tracking task. Pilot ratings were less consistent, however, ranging from 3 to 6 for the baseline and sensitive stick configurations, and from 5 to 8 for the time delay configuration. Pilot comments varied as well and depended largely on a pilot's operational background and preferred piloting technique. For instance, Pilot B, who had a fighter background, liked the sensitive stick configuration and gave it better ratings than did Pilot C, who had a transport aircraft background. Conversely, Pilot C consistently gave the added time delay configuration better ratings than did Pilot B, who found it nearly uncontrollable at times. This manifested itself in the pilot ratings as differences in perceived workload levels.

For the high- and low-fidelity HUD tracking tasks, Figure 22 shows vastly different ratings, ranging from 2 to 3 for the low-fidelity target and from 4 to 7 for the high-fidelity target. Reasons for the differences in ratings between the two targets were discussed in MOP 1.2, and in this case, were driven mostly by the tracking task performance criteria. Pilots were unable to achieve desired performance most of the time and frequently did not even achieve adequate performance for the high-fidelity HUD target. For the low-fidelity HUD target, pilots were able to achieve desired performance nearly all of the time, and the small rating differences were mostly due to different amounts of pilot workload. The R. Smith program did not take task performance into account.

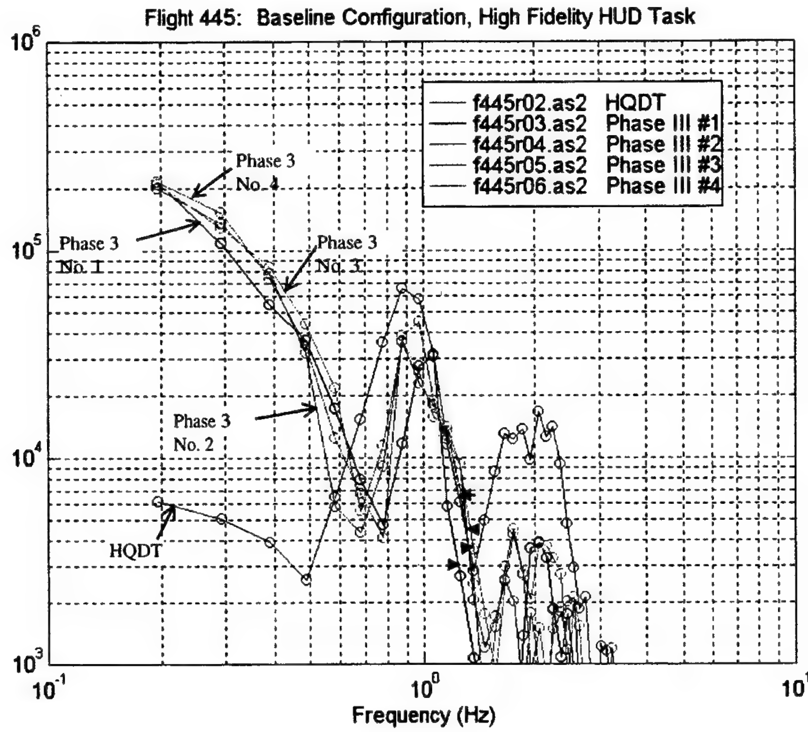
Results from the added time delay and sensitive stick configurations show similar results (Figures F4 and F5, Appendix F). The R. Smith criteria was a poor predictor for pilot ratings during operational tracking tasks.

For the second analytical method for pilot ratings, the HUD error signal was analyzed. Detailed results of each tracking task flown showing the percentage of time the pipper was held within 5, 10, and 25 mils of the HUD target are shown in Tables E3, E6, and E9 (Appendix E). Based on analysis of the error signal, pilots were able to accurately assess performance in accordance with the criteria 67 percent of the time as presented in Table 2. For the high-fidelity task, pilots only made "correct" assessments 56 percent of the time, while they were correct 84 percent of the time for the low-fidelity task. From pilot comments, the errors were due to two factors: first, the low-fidelity task was "easier" and less dynamic, making assessment of performance simpler. Second, the desired and adequate performance circles for the low-fidelity task were much larger (10 and 25 mils) than the high-fidelity circles (5 and 10 mils). The relative size of the pipper and the desired performance circle made performance assessment more difficult for high-fidelity HUD tracking task (2-mil pipper for a 5-mil target) than for the low-fidelity HUD tracking task (2-mil pipper for a 10-mil target.) Incidentally, Pilot B's assessment ability was much better than either Pilot A's or C's. This was attributable to his extensive fighter background and experience assessing tracking task performance, whereas Pilots A and C both had little experience assessing tracking performance during maneuvers. Using the HUD target tracking error signal made assessment of pilot performance easy.

Additionally, pilots commented that having the error signal displayed in the cockpit immediately following each maneuver would greatly simplify the rating process and would result in better (more accurate) pilot ratings.

Accurate pilot assessment of task performance requires training. The use of computer scoring techniques can aid in this training and make pilot assessment of task performance less critical. The use of real-time scoring would be particularly useful for this. **Incorporate computer-based scoring (real-time if possible) of task performance for aircraft HQ assessments whenever possible. (R5)**

Attempts to quantify workload using PSD plots were unsuccessful. Figure 23 shows one example of the many PSD plots generated throughout test program. Figure 23 is representative of the other PSD plots, presented later in this report.



Notes: 1. HUD - head-up display
2. HQDT - handling qualities during tracking

Figure 23 Sample Power Spectral Density Plot for Five Tracking Tasks

The planned method of determining pilot workload based on measurement of pilot bandwidth for each maneuver and comparing it to the pilot's bandwidth during HQDT was not possible. As previously described, bandwidth was defined as: frequency past the peak of the PSD at which the PSD has dropped by one order of magnitude. As can be seen from Figure 23, the pilot's bandwidth for HQDT was approximately 1.3 Hz. This was assumed to be the 'maximum attainable' physical workload, but this assumption was incorrect. Figure 23 shows nearly the same bandwidth for each of the phase 3 maneuvers, some of which had slightly higher bandwidth than that observed during HQDT. The expected result was a significantly lower bandwidth for the phase 3 maneuvers. Therefore, without a method of determining pilot workload, pilot ratings could not be estimated with any more accuracy than a general HQ level (level 1, 2 or 3).

Pilot bandwidth (as defined in this report) during phase 3 operational tracking tasks relative to pilot bandwidth during HQDT maneuvers did not provide a measure of pilot physical workload suitable for use in HQ evaluations.

Having the HUD error signal did however allow an interesting investigation into the effects of varying the tracking task and performance criteria. This was in the form of a sensitivity analysis on pilot ratings during HUD tracking tasks.

Because the low-fidelity task was considered "easier" by the pilots, if the more strict performance criteria had been used (5 mils for desired performance and 10 mils for adequate - see Table 2), pilot performance should have decreased. Likewise, if performance for the more difficult, high-fidelity task had been measured using the low-fidelity task criteria (10 mils for desired performance and 25 mils for adequate) performance should have improved. By using the error signal percentages shown in Tables E3, E6, and E9 (Appendix E), it was possible to evaluate this effect.

To show the difference a change in criteria would make, pilot ratings were adjusted based on the error signal results with the different performance criteria applied. Workload assessment was from pilot comments previously given during each tracking task. Figure 24 shows the decision

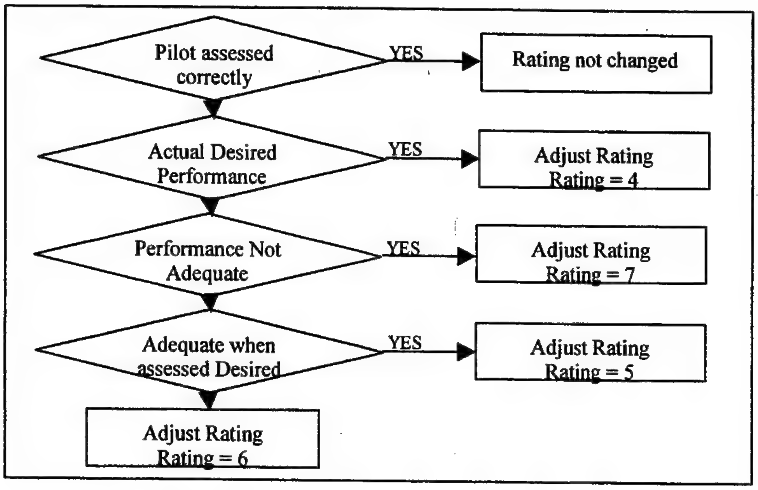


Figure 24 Decision Tree for Adjusting Pilot Ratings

task performance criteria on pilot ratings, based on pilot workload being the same as the pilot originally rated it. So, for instance if the pilot said he achieved desired performance and rated the workload as "moderate," he would have most likely rated the aircraft a 4 on the Cooper-Harper scale. But, if using different criteria, he would have gotten adequate performance instead, his rating would have been a 5. This left the workload assessment reasonably constant with a change only in performance.

The results of using the Table 2 high-fidelity criteria for the low-fidelity task and low-fidelity criteria for the high-fidelity task are also shown in Figure 25, middle column. As can be seen, ratings for the high-fidelity task dropped (from 5 to 7 to 4 to 6) while ratings for the low-fidelity task did not change considerably. This was more pronounced for the added time delay configuration and the sensitive stick configuration (Figures F4 and F5, Appendix F). The ratings for the high-fidelity task when using the adjusted criteria were much closer to those for the 'truth source' T-38 ratings in all cases. The ratings for the low-fidelity task remained relatively unchanged.

Using a HUD error signal was an excellent tool. It was useful in predicting general HQ levels (level 1, 2 or 3) although not exact ratings. It also enabled postflight investigation of the effects of varied task performance criteria and gave the pilots feedback as to how well they were rating performance.

This capability would be especially useful during a detailed aircraft HQ analysis when trying to develop realistic task criteria. The exercise in changing performance criteria described above, showed how changing tracking task performance criteria could affect HQRs. The fact that adjusted ratings for the high-fidelity target were very similar to those for the T-38 target and the adjusted low-fidelity ratings were not similar to those for the T-38 target may indicate that the low-fidelity task criteria was poor and that the high-fidelity tracking task may be improved by changing performance criteria. Having the HUD error signal enabled this evaluation.

Objective 3: Evaluate Analytical Methods for Showing Learning Curve:

Objective 3 was met. Only three repetitions were conducted with the actual target for some of the pilots, which was less than the desired four repetitions, but was still adequate for evaluation of the objective. While the pilots' comments on workload were not quantified into five levels, the pilot's recorded qualitative comments of each maneuver gave a descriptive monologue of their workload. There was one MOP for this objective, analytic methods versus pilot ratings.

MOP 3.1 – Analytical Methods versus Pilot Ratings.

The purpose of this MOP was to compare analytical methods for determine pilot physical workload to the results obtained from pilot comments and ratings. As in MOP 2.2, the HUD error signal was used to measure performance and the PSD of pilot pitch inputs was used to measure workload during the evaluation of the learning curve effects.

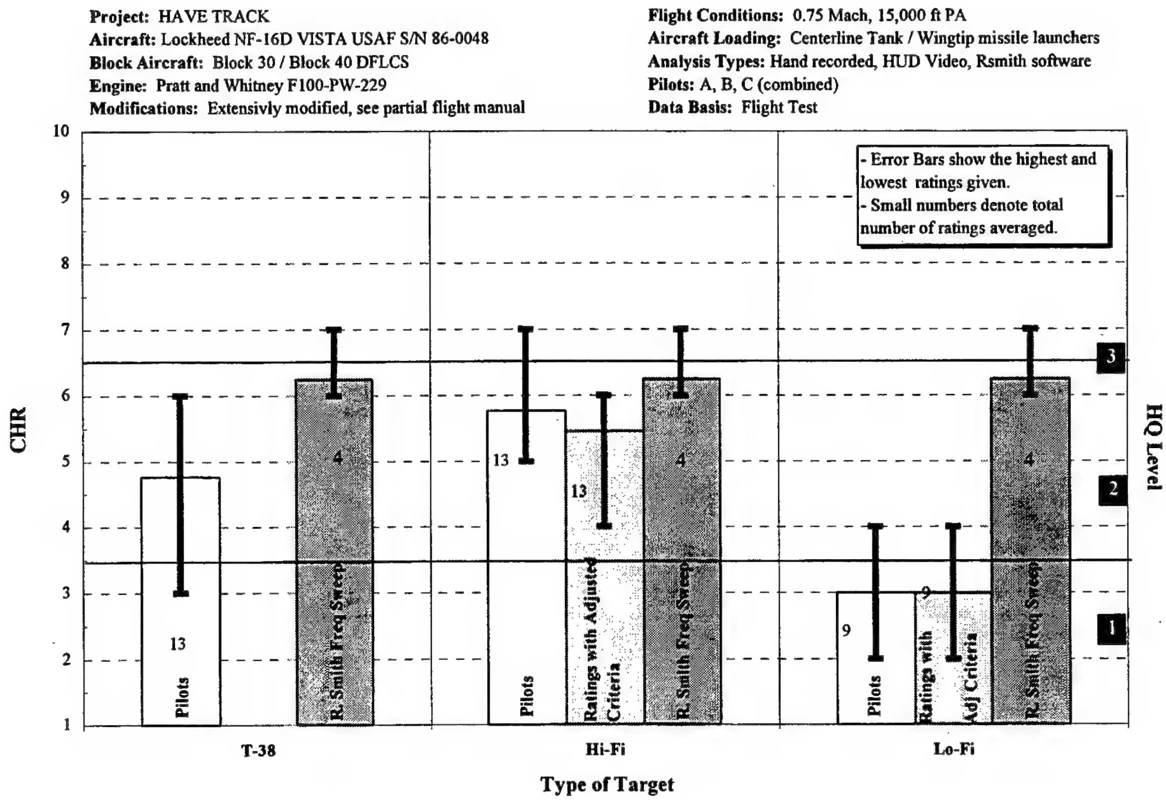


Figure 25 Comparison of Pilot Cooper-Harper Ratings (CHRs) Using Adjusted Task Criteria, Baseline Flight Control Configuration

Test Procedures

As with the previous MOPs, the VISTA was flown against the low-fidelity HUD target, the high-fidelity HUD target, and the actual target. For each of these targets the F-16 VISTA was programmed for the three different FCCs. Pilots flew the same phase 3 evaluation tasks multiple times against each of the three targets for each of the three FCCs. Pilot's PIOR, CHR, HUD target tracking error, and pitch stick inputs were recorded during each maneuver. Quantified error plots and pilot's pitch stick PSD plots were generated from the recorded data. The error was quantified as the percentage of time the pilot was able to keep the pipper inside the 5-, 10-, and 25-mils circles. For a comparison to maximum physical workload, HQDT maneuvers performed as part of objectives 1 and 2 were also analyzed.

Test Results

Three different analytical tools were used to display the pilot's learning curve during successive repetitions of a tracking task for each FCC. The three different analytical tools were the quantified error, CHRs, and the pitch stick input PSD. Figures 26 and 27 show the quantified error and CHR for the baseline configuration. Figures 28 and 29 show the quantified error and CHR for the sensitive stick configuration. Figures 30 and 31 show the quantified error and CHR for the time delay configuration. Representative PSD plots for each pilot, FCC, and tracking task may be found later in this report.

The CHR and quantified error were used primarily to evaluate task performance. For each of the configurations, the general trend for CHR and quantified error was a slight or negligible performance increase for successive tasks. The CHR tended to follow the quantified error. In fact, there were several performance reversals.

As a tracking task was repeated, the pilot performance was not consistently improving. From the quantified error data, the largest single factor affecting performance was the pilot. The performance between pilots was vastly different. Coincidentally, the previous flying experience of the pilots was also vastly different. Pilot A came from a trainer/bomber background; Pilot B came

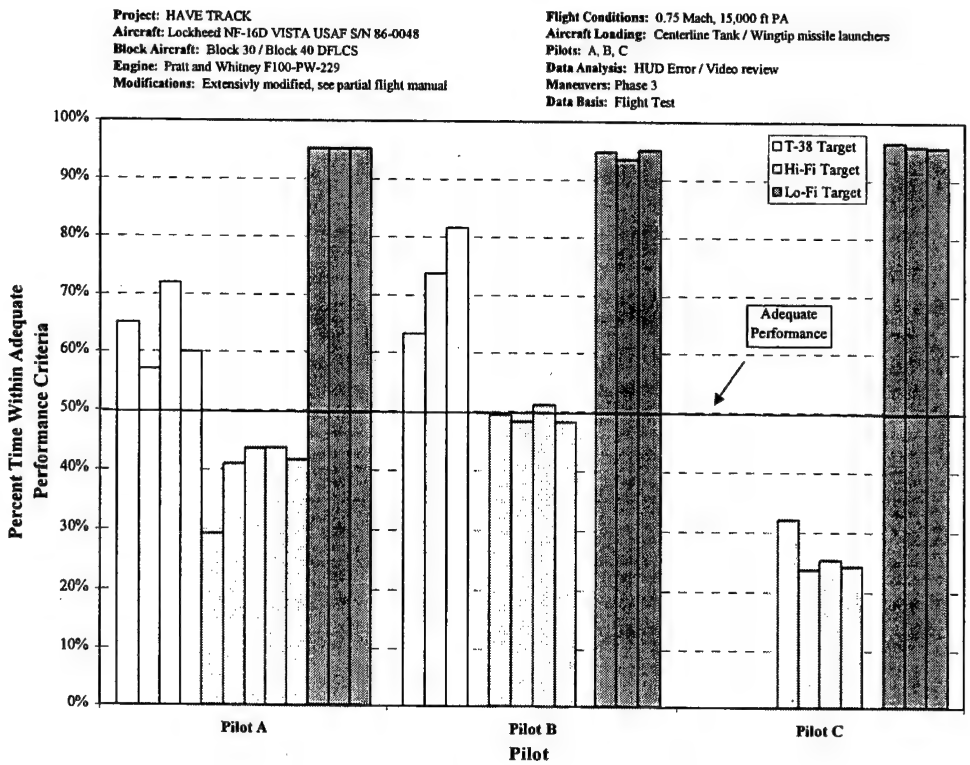


Figure 26 Learning Curve Effects on Pilot Performance: Baseline Flight Control Configuration

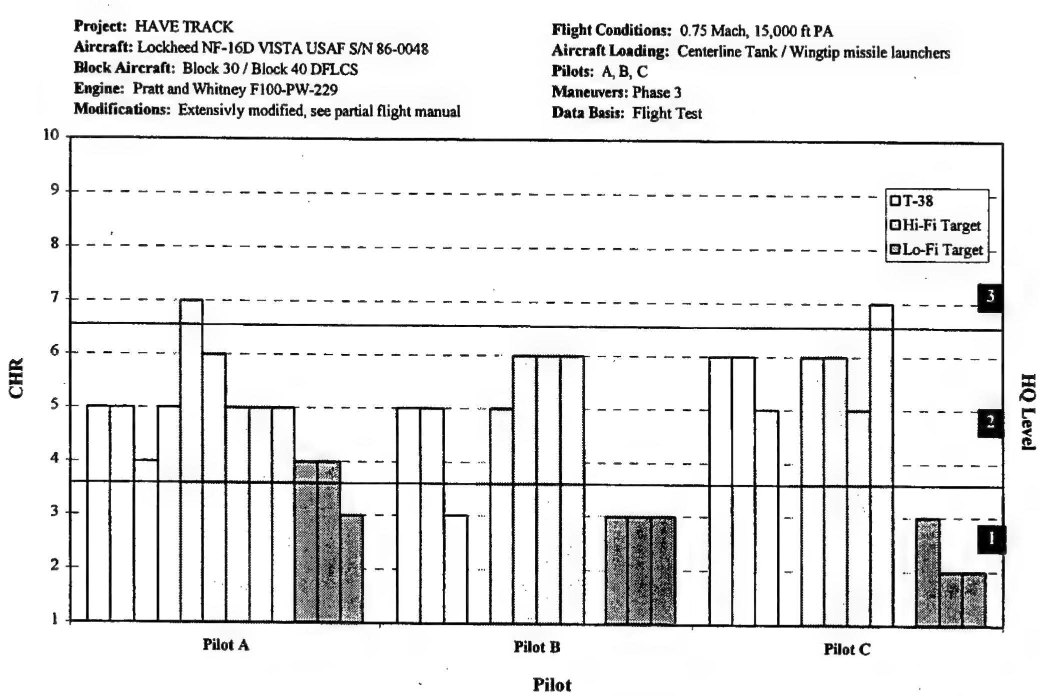


Figure 27 Learning Curve Effects on Pilot Rating: Baseline Flight Control Configuration

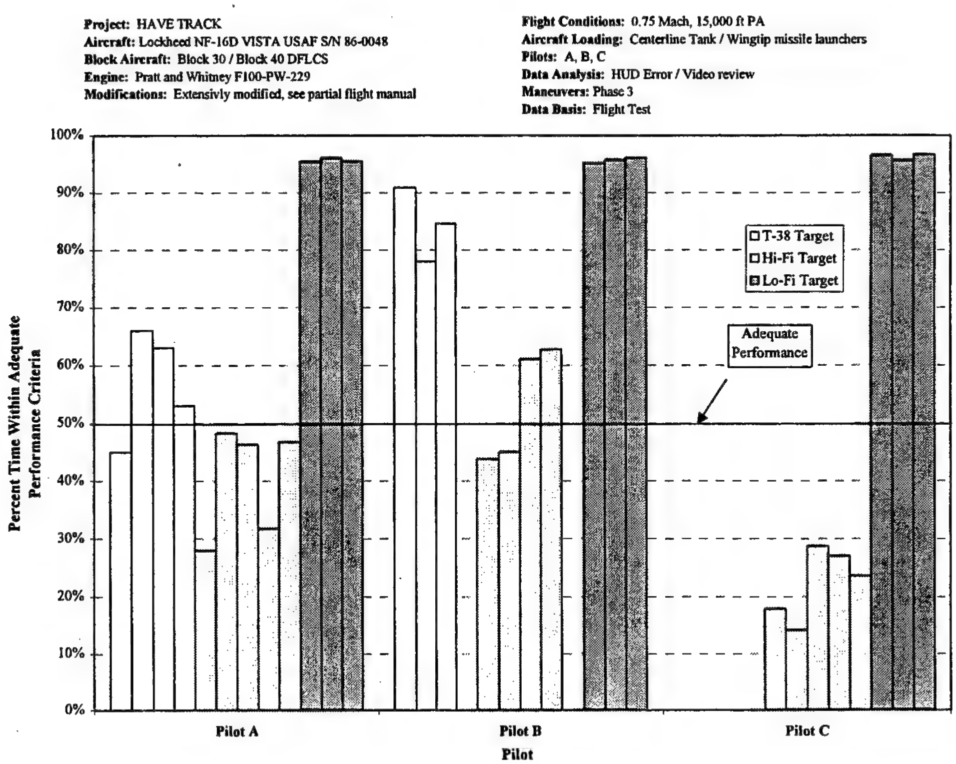


Figure 28 Learning Curve Effects on Pilot Performance: Sensitive Stick Flight Control Configuration

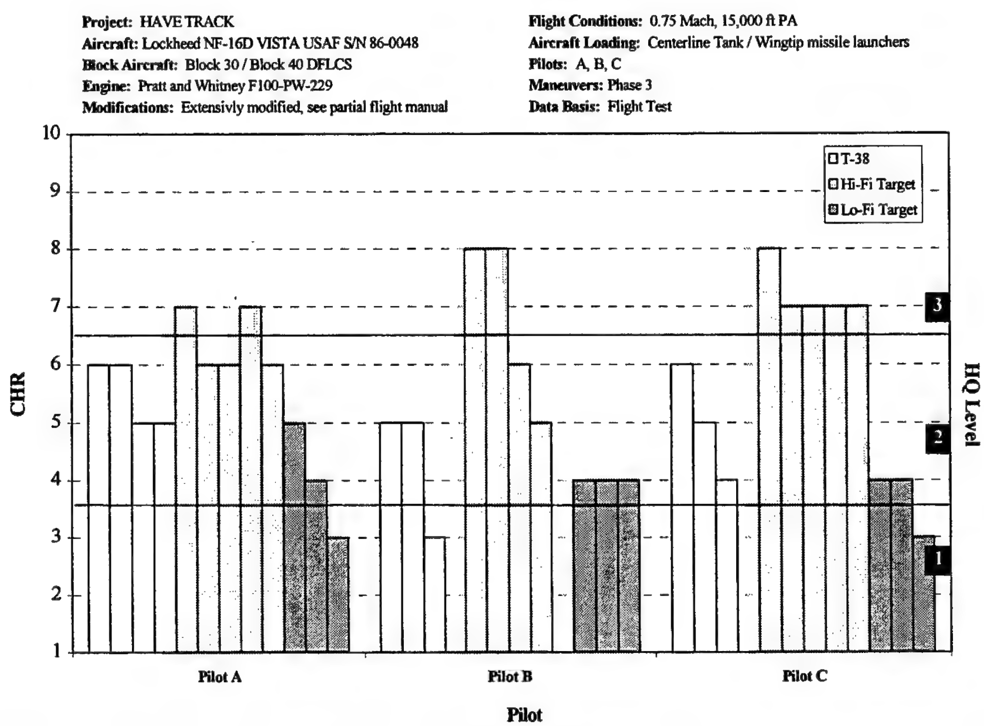


Figure 29 Learning Curve Effects on Pilot Rating: Sensitive Stick Flight Control Configuration

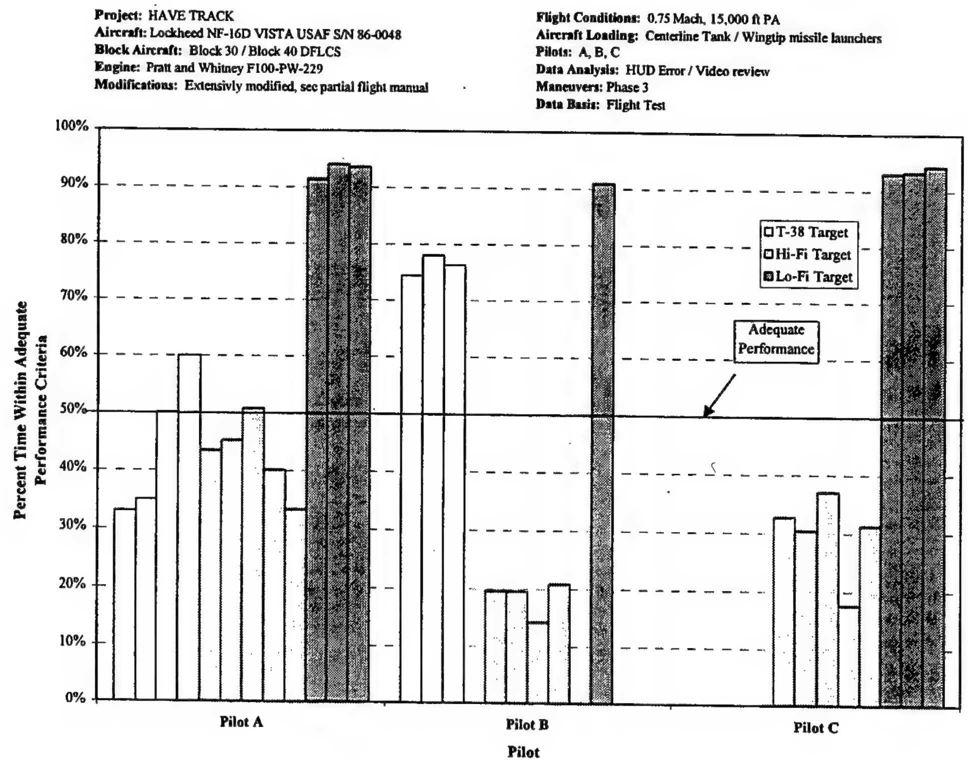


Figure 30 Learning Curve Effects on Pilot Performance: Added Time Delay Flight Control Configuration

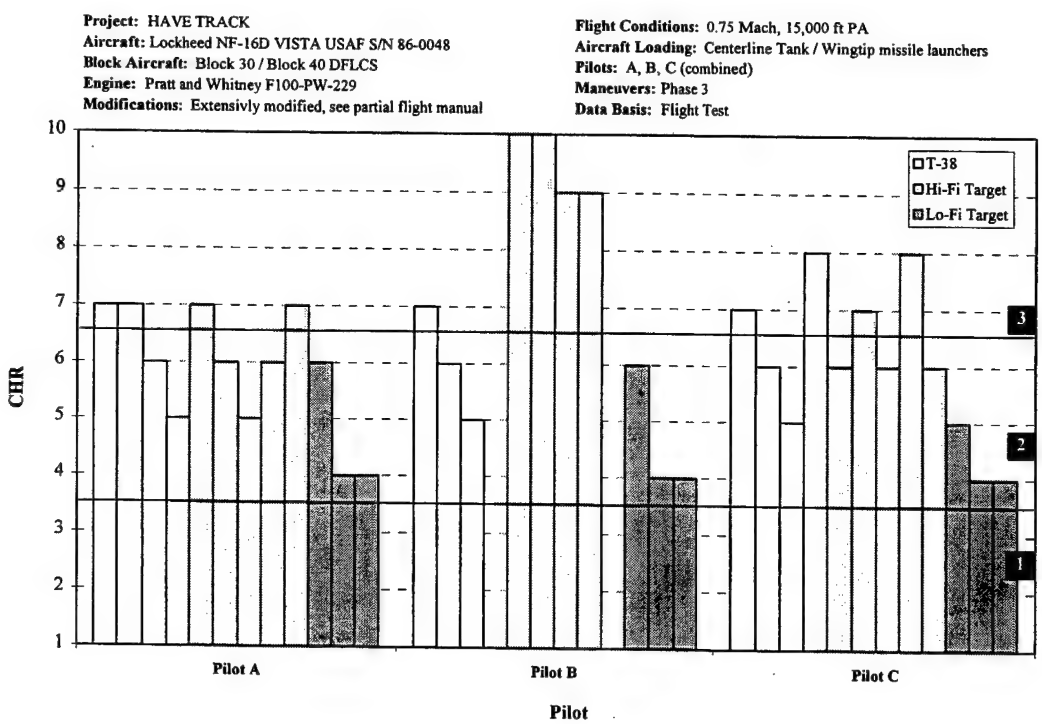


Figure 31 Learning Curve Effects on Pilot Rating: Added Time Delay Flight Control Configuration

from a fighter background; and Pilot C came from a transport/utility background. The previous flying experience of the pilots therefore could have affected the task performance. If both the task performance and pilot workload, the basis of handling quality (phase 3) evaluations, were affected by the pilot's background, then the handling quality evaluation would be biased by the pilot's previous flying background.

The analysis of pilot workload was based on the assumption that total workload could be broken into mental and physical workload, and the physical workload of the pilot would be proportional to the bandwidth the PSD of control inputs. Mental workload assessment would then be based on pilot comments. Pilot C, with previous experience in aircraft with substantial time delay, applied low-frequency open-loop inputs for the time delay configuration with the high-fidelity and actual target tasks. This type of compensation resulted in the best performance, although it was barely adequate. Pilot C commented that the average of pitch or roll oscillations was easy to control, but limiting the size of the oscillations led to a PIO in pitch and roll. Pilot A, who also had experience in aircraft with substantial time delay, immediately realized these limitations of the time delay configuration. The previous experience of these pilots resulted in minimal learning curve past applying open-loop inputs. Pilot B, with fighter aircraft background, found the time delay configuration barely controllable at times, and found the aircraft difficult to control in both the pitch and lateral axes. Pilot B did however demonstrate a dramatic learning curve between his first sortie involving the time delay FCC (against the high-fidelity HUD target) and his second sortie involving the time delay FCC (against the actual aircraft target.) Similarly, Pilot C, with little experience in aircraft with a sensitive stick, found the sensitive stick FCC divergent during the tracking tasks, and commented on constantly abandoning the tracking task to maintain control. Pilot B, fighter background, noted that the sensitive stick FCC did everything he commanded it to do, very predictably, when the aircraft was under 3 g's or the when stick was well away from the friction and breakout point. Thus, both pilot performance and pilot workload were heavily affected by the pilot's previous flying experience.

Previous experience of the pilot can affect pilot workload, task performance, and even the stability of an aircraft during tracking tasks. This effect can mask learning curve effects for tasks that are only repeated a few times. It can also heavily influence handling quality (phase 3) evaluations. **In order to minimize the effects of previous pilot background during the handling quality (phase 3) evaluations, use pilots with similar previous experience. For example, all pilots with a fighter aircraft background or all pilots with a heavy aircraft background. (R6)**

From pilot comments, several other factors could have affected pilot's performance. These factors included lateral offset corrections, physical fatigue and frustration (mental fatigue), and learning curve affects between configurations.

The actual target and high-fidelity tracking tasks required both a gross acquisition and fine tracking solution to be solved in both the lateral and pitch axes. The low-fidelity task did not require this two axis solution, since the bank angle did not affect the adequate/desired criteria. For all pilots, the sensitive stick configuration allowed quicker gross acquisition but had more fine tracking oscillations. This can be seen from the data, Table E6 (Appendix E), as the 25-mil quantified error percentage was higher for the sensitive stick configuration than either the baseline or the time delay configurations (Tables E3 and E9). All pilots solved the bank first before narrowing in on the pitch solution. The lateral solution tended to be tougher initially after target roll-in or reversal due to the varying pendulum effect of the gunsight. Both Pilot A and Pilot B commented that matching the bank angle of the target on roll-in tended to result in the best performance. By making the lateral solution easier, the pitch performance would improve. Based on pilot comments, most of the learning from task to task was associated with solving the lateral control problem. Once bank was solved, the pilot could concentrate his effort on the pitch axis. In some cases, a poor initial bank acquisition made the task performance criteria impossible. Pilot performance did not always improve as a task was repeated. As pilots experimented with differing tracking techniques, sometimes performance improved, sometimes it did not. For example, in some cases the pilot's initial estimate of the correct bank angle for tracking the target was correct and the lateral problem was immediately solved. In other cases, this initial estimate was incorrect and additional effort was required to solve the lateral problem.

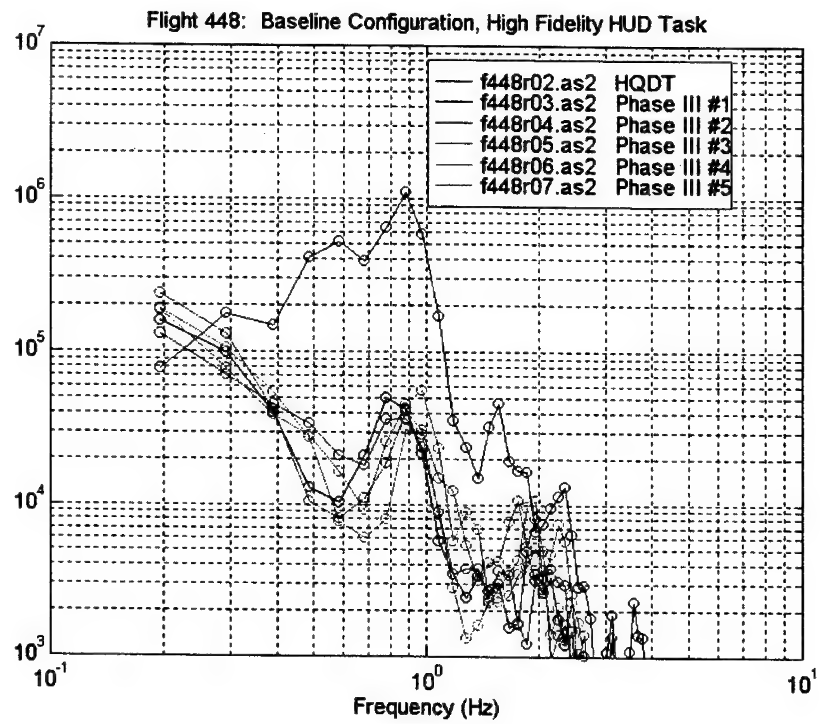
Another reason for performance setbacks could have been pilot fatigue. Fatigue was characterized by decreased pilot compensation, increased physical workload, and degraded task performance. Figure 28 shows that for Pilot C's final task, quantified error

increased for the sensitive stick configuration with the high-fidelity task. Based on pilot comments this was due directly to fatigue. Pilot B noted that with the low-fidelity task and the baseline FCC that if he did not see performance improvement (a learning curve) that mental fatigue (apathy or frustration) manifested in much the same was as physical fatigue noted by Pilot C. Pilot A found the same effect with the time delay configuration and high-fidelity target.

The learning curve for the baseline configuration could have influenced the performance for the sensitive stick configuration for each of the three pilots. In other words, if the sensitive stick configuration were tested prior to the baseline configuration, then better overall performance might have been obtained on the baseline configuration. Pilot A noted he flew the lateral solution better for the sensitive stick configuration than the baseline configuration for the high-fidelity task. Pilot A also flew one more task with the baseline configuration near the end of the high-fidelity target sortie after flying numerous tasks in each of the three configurations. His performance had improved over the performance at the beginning of the sortie.

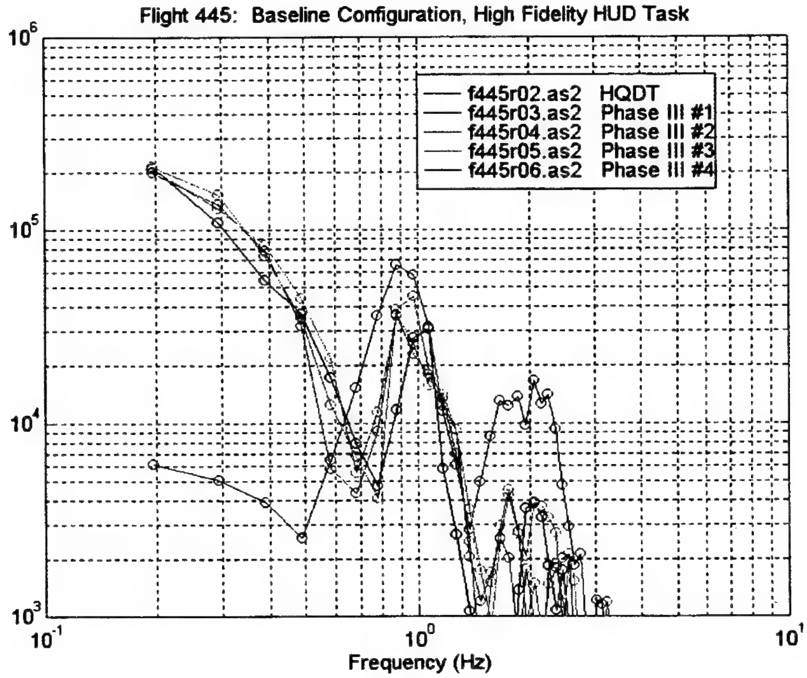
Example PSDs which are representative of the different pilot, tracking task, and FCC combinations are shown in Figures 32 through 35. The PSDs for successive tasks were generally inconclusive for determining pilot physical workload. There did not appear to be a general reduction in the pilot's frequency content as performance increased. However, certain phase 3 PSD plots tended to scatter more than others. This was usually when the pilot was unfamiliar with the configuration and was searching for the best form of compensation. This was particularly true for Pilot B and time delay configuration (high-fidelity target) as shown in Figure 35.

This may have been because the tasks were too difficult, since for this evaluation, the pilot's workload was the same for each task. This was true when less than desired performance was attained. Simply, the pilots worked as hard as possible until desired performance was attained. Since desired performance was rarely obtained for the high-fidelity target, change in workload was not perceivable by the pilots. Only with the T-38 target, did both Pilot B and Pilot C comment on less workload when desired performance was achieved.



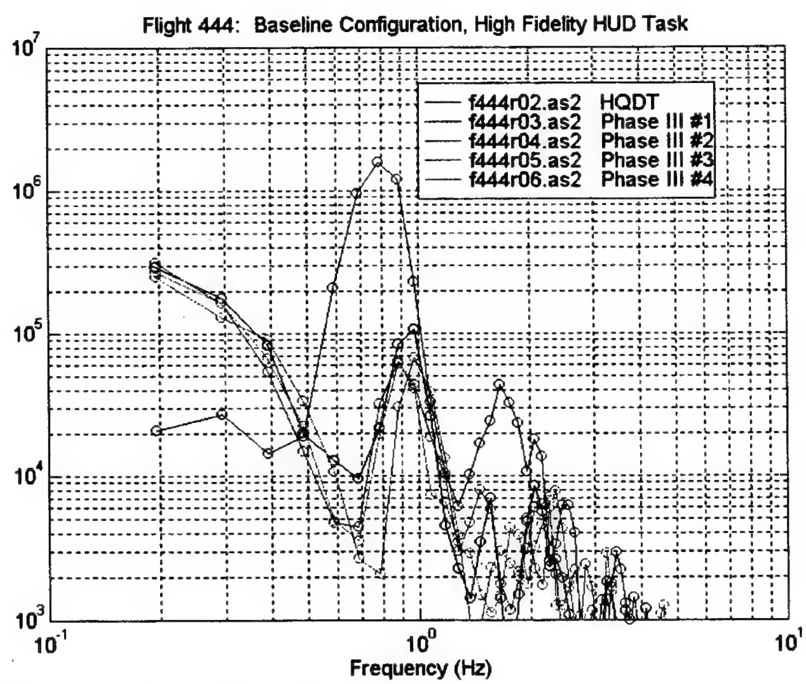
Notes: 1. HUD - head-up display
2. HQDT - handling qualities during tracking

Figure 32 Power Spectral Density for Flight 448, Baseline Flight Control Configuration (Pilot A)



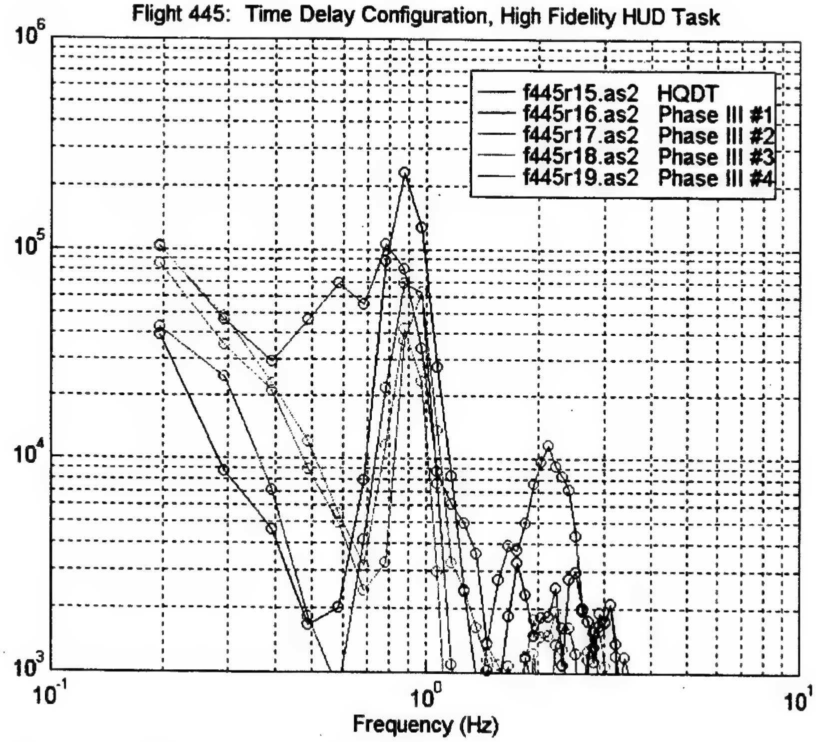
Notes: 1. HUD - head-up display
2. HQDT - handling qualities during tracking

Figure 33 Power Spectral Density for Flight 445, Baseline Flight Control Configuration (Pilot B)



Notes: 1. HUD - head-up display
2. HQDT - handling qualities during tracking

Figure 34 Power Spectral Density for Flight 444, Baseline Flight Control Configuration (Pilot C)



Notes: 1. HUD - head-up display
2. HQDT - handling qualities during tracking

Figure 35 Power Spectral Density for Flight 445, Time Delay Configuration (Pilot B)

One trend of interest, however, was that for the different pilots, the PSDs were very similar in frequency and absolute gain for all of the configurations and tasks. For the baseline configuration, the frequency for the major lobe was 0.95 Hz for all three pilots. Assuming the frequency content of the PSD was a direct reflection of the pilot's compensation, the aircraft configuration and the task and criteria tended to determine the type of compensation applied, not the pilot.

The different pilots converged to similar PSDs for a given tracking task and FCC combination. When the PSD phase 3 plots converge, this probably indicated the pilot had settled on a type of compensation. In some cases this happened on the second phase 3 tracking task (i.e., based on previous experience the pilot had decided on a control technique and was no longer modifying it). In other cases the limited number of task repetitions did not allow the pilot to settle on a specific technique. Learning required modifying the tracking technique slightly, and determining what improved performance and what did not.

Finally, PSDs that were very similar to the HQDT could indicate minimal pilot compensation. A good example of this was flight 444 and the sensitive stick configuration. After 1 Hz, the PSDs for the HQDT and phase 3 tasks were very similar. Coincidentally, the pilot commented he had to "exit the loop" routinely during this PIO-prone configuration.

Other Results

One specific benefit of using HUD tracking tasks was identified during the test procedure. More test points could be accomplished in less time with the HUD task than could be accomplished using an actual aircraft target, this was because there was no requirement to maneuver the target aircraft into position prior to beginning the tracking task. There was also a scheduling benefit to requiring only the test aircraft to perform test points. This resulted in a 33-percent increase in the number of test points accomplished on missions involving HUD tracking tasks versus missions involving tracking an actual target.

The use of HUD tracking tasks greatly reduced the complexity of organizing repeated scripted maneuvers between multiple aircraft. This increased the percentage of flight time that was spent on data collection by 33 percent.

CONCLUSIONS AND RECOMMENDATIONS

The head-up display (HUD) tasks, combined with handling qualities during tracking (HQDT), were successful in predicting pilot-induced oscillation (PIO) susceptibility. The correlation from configuration to configuration showed that the HUD targets resulted in the same characterization of PIO as the actual target, either prone [pilot-induced oscillation rating (PIOR) 4 or worse] or not prone (PIOR of 3 or better) in all but 2 of the 18 comparisons.

For the configurations tested, the lateral motions of the pipper were large enough that they affected task performance and could not simply be ignored in flight.

Differing pilot HQDT techniques would not have been discovered without the aid of the HUD tracking tasks and the associated tracking task error signals.

> ***1. To standardize HQDT techniques, train test pilots using an aircraft or simulator that can display tracking error time traces relative to pilot stick inputs. (Page 12)***

The best HQDT technique for consistently classifying the PIO susceptibility of an aircraft was the proportional amplitude technique, reversing at zero error, with as close to a step input as possible.

> ***2. Accomplish additional testing to quantify the advantages of proportional amplitude HQDT technique for identifying PIO susceptibility. (Page 13)***

Phase 3 tasks and HUD-generated targets may or may not be useful in determining PIORs. There was weak correlation for the baseline and sensitive stick cases and none for the time delay case. The results were indeterminate.

Phase 3 tasks and HUD generated targets may or may not be useful in determining Cooper-Harper ratings (CHRs). The results were indeterminate. A higher fidelity HUD task may result in a better match of CHRs between the actual target tracking and HUD target tracking.

> ***3. Accomplish additional testing on a more accurate, higher fidelity, HUD target model. (Page 14)***

The 1 through 6 PIO tendency scale presented in Appendix B has ambiguities that make it inappropriate for use with the HQDT maneuver.

> ***4. Develop a specific rating scale for use with HQDT that allows ratings of: not PIO prone; PIO prone with bounded oscillations; or PIO prone with divergent oscillations. (Page 21)***

Except in cases where stick sensitivity was the source of PIO, predictions from the R. Smith criteria correlated well with pilot ratings following HQDT maneuvers as PIO prone or not. R. Smith predictions tended to be conservative (worse than pilot ratings) for phase 3 tracking tasks, but not in all cases. The R. Smith program was therefore a satisfactory predictor of PIO susceptibility from aircraft open-loop frequency response.

Phase 3 tracking tasks should not be relied upon for assessing PIO susceptibility because pilot bandwidth may not be sufficient to excite PIO during such tasks.

Frequency sweeps provided the most consistent data for the R. Smith program to predict aircraft HQRs.

The R. Smith criteria was a poor predictor for pilot ratings during operational tracking tasks.

Accurate pilot assessment of task performance requires training. The use of computer scoring techniques can aid in this training and make pilot assessment of task performance less critical. The use of real-time scoring would be particularly useful for this.

> ***5. Incorporate computer-based scoring (real-time if possible) of task performance for aircraft HQ assessments whenever possible. (Page 24)***

Pilot bandwidth during phase 3 operational tracking tasks relative to pilot bandwidth during HQDT maneuvers did not provide a measure of pilot physical workload suitable for use in HQ evaluations.

Using a HUD error signal was an excellent tool. It was useful in predicting general HQ levels (level 1, 2 or 3) although not exact ratings. It also enabled postflight investigation of the effects of varied task performance criteria and gave the pilots feedback as to how well they were rating performance.

As a tracking task was repeated, pilot performance was not consistently improving.

Previous experience of the pilot can affect pilot workload, task performance, and even the stability of an aircraft during tracking tasks. This effect can mask learning curve effects for tasks that are only repeated a few times. It can also heavily influence handling quality (phase 3) evaluations.

6. In order to minimize the effects of previous pilot background during the handling quality (phase 3) evaluations, use pilots with similar previous experience. For example, all pilots with a fighter aircraft background or all pilots with a heavy aircraft background. (Page 31)

With task repetition, the different pilots converged to similar PSDs for a given tracking task and FCC combination.

The use of HUD tracking tasks greatly reduced the complexity of organizing repeated scripted maneuvers between multiple aircraft. This increased the percentage of flight time that was spent on data collection by 33 percent.

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APPENDIX A

AIRCRAFT FLIGHT CONTROL CONFIGURATIONS

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AIRCRAFT FLIGHT CONTROL CONFIGURATIONS

The test aircraft will have multiple flight control configurations (FCCs) programmed into the variable stability system. The Variable Stability In-flight Simulator Test Aircraft FCC used during the HAVE TRACK flight test project will be derived from the configurations tested under the HAVE FILTER flight test project (see Section 1.2.2). The lower order equivalent systems and control anticipation parameters of the FCCs, HAFA 1 used under the HAVE FILTER flight test project was:

where for HAFA 1: (designed for 300 knots, 15,000 ft)

$$\frac{q_{loes}}{\delta_{des}} = \frac{(K)(T_{\theta 2}s+1)e^{-\tau_d s}}{(s^2+2\zeta_{sp}\omega_{sp}s+\omega_{sp}^2)} \quad (1)$$

$$CAP = \frac{g\omega_{sp}^2 T_{\theta 2}}{V_{T_0}} \quad (2)$$

$$K = 18.998 \qquad T_{\theta 2} = 0.65 \quad (3)$$

$$\tau_d = 0.156 \qquad \omega_{sp} = 4.64 \quad (4)$$

$$\zeta_{sp} = 0.7 \quad CAP = 0.718\sec^2 \quad (5)$$

The baseline FCC used under this project was the lower order equivalent system shown above, designed for 0.75 Mach and 15,000 ft. The time delay FCC had an additional 200 milliseconds of time delay in both the pitch axis and 60 milliseconds in the roll axis. The sensitive stick case had an added stick gain of 2.67 in the pitch axis and 2.0 in the roll axis. A block diagram of the aircraft FCC is shown in Figure A1. During the two calibration flights and the verification flight, a baseline aircraft would be identified. The baseline configuration was selected based on Cooper-Harper ratings obtained during handling tasks using the programmed head-up display profiles.

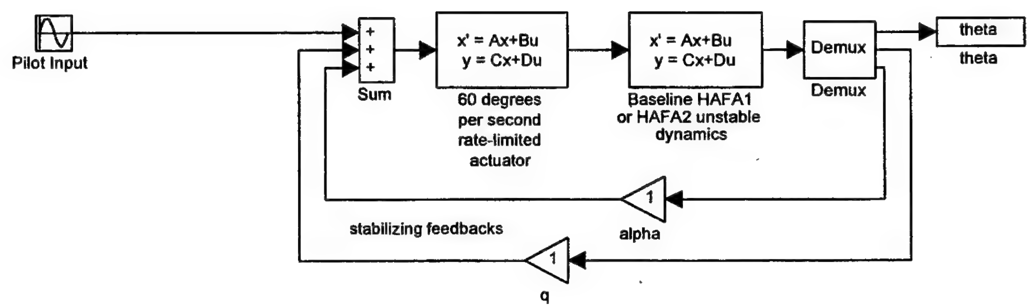

Figure A1 Block Diagram of HAVE FILTER Variable Stability In-Flight Simulator Test Aircraft (VISTA) Flight Control Configuration (FCC)

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APPENDIX B

RATING SCALES

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RATING SCALES

The Cooper-Harper Rating (CHR) Scale (Figure B1) and the Pilot-induced Oscillation (PIO) Tendency Scale (Figure B2) contained here were extracted from Reference 1.

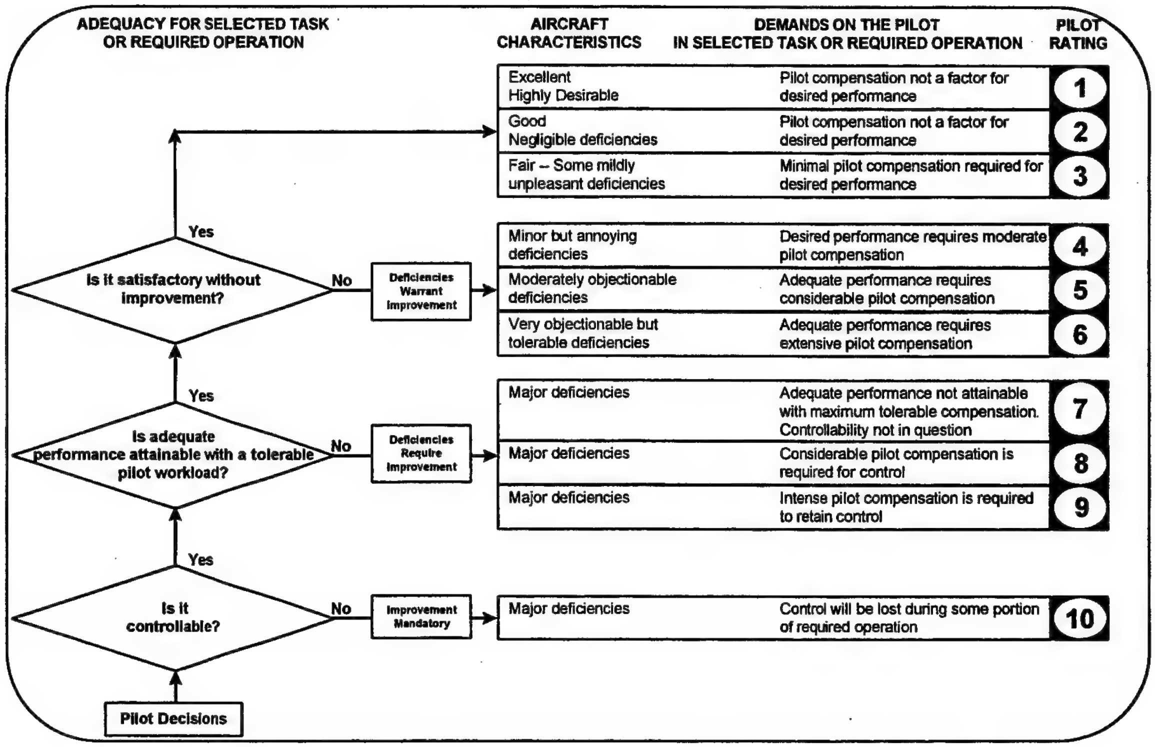

Figure B1 Cooper-Harper Rating (CHR) Scale

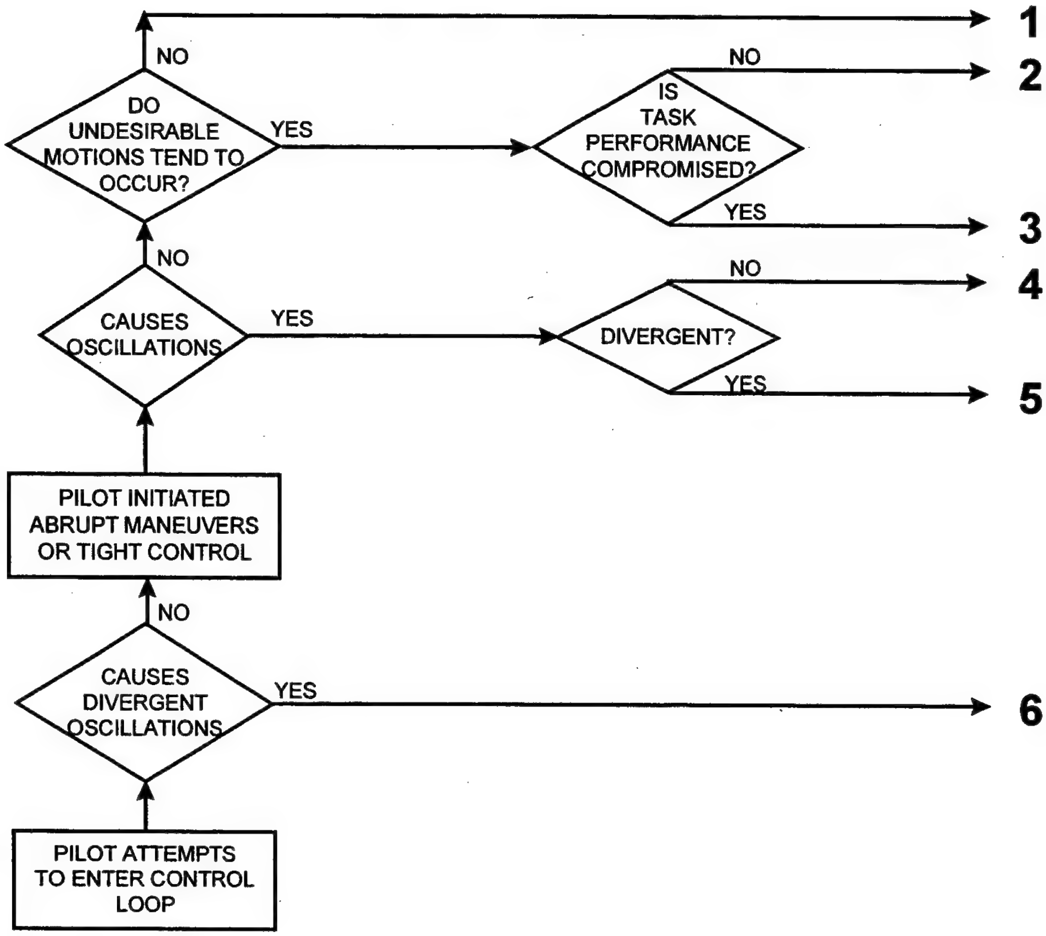

Figure B2 Pilot-Induced Oscillation (PIO) Tendency Scale

APPENDIX C

VARIABLE STABILITY IN-FLIGHT SIMULATOR TEST AIRCRAFT (VISTA) INSTRUMENTATION

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VARIABLE STABILITY IN-FLIGHT SIMULATOR TEST AIRCRAFT (VISTA) INSTRUMENTATION

Data required from the VISTA included time, altitude, airspeed, normal acceleration (N_z), roll rate (p), roll angle (φ), pitch rate (q), pitch angle (θ), head-up display (HUD) error signal between the HUD-generated target and the pipper, airspeed, altitude, and stick forces. All of these parameters were available through the normal VISTA instrumentation.

For all test sorties, a HUD tape was required as backup to pilot comments on task performance. The HUD tape included audio communications. All data were tagged with an event marker and was verbally identified on the HUD tape.

No instrumentation modifications were required. Calspan was responsible for all instrumentation requirements. Table C1 shows the data parameters recorded on board the F-16 VISTA during each aircraft test maneuver.

Table C1
DATA PARAMETERS RECORDED ON BOARD THE F-16 VARIABLE STABILITY IN-FLIGHT SIMULATOR TEST AIRCRAFT (VISTA)

Parameter	Description
huderrlat	lateral error between pipper and head-up display (HUD) target in Mils
huderrlon	vertical error between pipper and HUD target in Mils
TT_R_ERR	bank error between aircraft and HUD target
VCAS	calibrated airspeed in knots
Vt	true airspeed in knots
MACH	MACH
ALPHA	angle of attack in degrees
NZ	g acceleration nearest the aircraft center of gravity
nz-pilot	g acceleration from the sensor nearest the pilot
pitchforce	longitudinal stick force in pounds
rollforce	lateral stick force in pounds
deles	longitudinal stick deflection in inches
delas	lateral stick deflection in inches
p	roll rate in degrees/second
q	pitch rate in degrees/second
THETA	pitch angle in degrees
ALT	altitude in feet
PTI	programmed test input to stick in inches
LHS_SYNCRO	left horizontal stabilizer synchronizer position in degrees
RHS_SYNCRO	right horizontal stabilizer synchronizer position in degrees
LFP_SYNCRO	left flaperon synchronizer position in degrees
RFP_SYNCRO	right flaperon synchronizer position in degrees
LHTCMD_1	left horizontal stabilizer commanded position in degrees
RHTCMD_1	right horizontal stabilizer commanded position in degrees
LFPCMD_1	left flaperon commanded position in degrees
RFPCMD_1	right flaperon commanded position in degrees
PHI	bank angle in degrees

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APPENDIX D

DAILY FLIGHT REPORTS

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DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	86-0048
VISTA NF-16	86-0048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE TRACK / VISTA #443	Flight #1	17 Mar 99
D. FRONT COCKPIT *(Left Seat)*	E. FUEL LOAD	F. JON
Christensen	7,600	M94C1400
G. REAR COCKPIT *(Right Seat and rest of crew)*	H. START UP GR WT / CG	I. WEATHER
Peer		CAVU
J. TO TIME / SORTIE TIME	K. CONFIGURATION / LOADING	L. SURFACE CONDITIONS
1020L / 1.3	Ctrline Tank	230/10G15
M. TARGET ACFT / SERIAL NO	N. TARGET CREW	O. TARGET TO TIME / SORTIE TIME
N/A	N/A	N/A

4. PURPOSE OF FLIGHT / TEST POINTS

1. Verify Reticle Depression for High Fidelity Task minimizes pendulum effect.
2. Verify High Fidelity Virtual Target – choose Altitude or Pitch Stabilized Target.
3. Verify Low Fidelity Virtual Target task gain.
4. Verify Sensitive Stick and Time Delay Configurations give degraded handling qualities.
5. Verify VSS will not trip off during Phase 2 and 3 tracking tasks for each target and configuration.
6. Perform 3 g pitch frequency sweeps for each configuration for frequency response analysis.
7. Perform constant roll rate aileron rolls to investigate PDS time delay.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Most objectives were met. Due to VSS trouble shooting during verification of the Time Delay Configuration, I was unable to accomplish the Low Fidelity Task of frequency sweep for this configuration. Although I was only able to fly one High Fidelity Task with this configuration, I was satisfied with the final Time Delay Configuration. All VSS configurations and PDS tasks ware ready for flight test.

Altimeter was set to 29.92 for all test points. During Phase 1 inputs with the baseline configuration, the rudder pedals were extremely sensitive. All subsequent handling qualities tasks were accomplished with feet on the floor.

The default reticle depression was set 15 mils above a point depressed 6° from the guncross. During a level 3 g turn, I verified that this reticle setting placed the pipper over the flight path marker and minimized pendulum effect. The 3 g turn was accomplished two more times during the mission. Changes in aircraft gross weight did not appear to change the angle of attack during these turns.

The following summarizes HQRs and PIORs for each run:

Config	Target	HQDT PIOR	Ph 3 PIOR	PH 3 HQR
Baseline	Hi Fi – Pitch Stab	<4	1	4
Baseline	Hi Fi – Alt Stab	<4	3	5
Baseline	Lo Fi	<4	2	2
Sensitive	Hi Fi – Alt Stab	4	4	6
Sensitive	Lo Fi	4	4	5
Delay	Hi Fi – Alt Stab	4	4	6

When flying against the Pitch Stabilized High Fidelity Target, the lateral axis was very stable, but was not considered representative of an actual target holding a constant altitude. The Altitude Stabilized target appeared to be more representative of an actual target since it moved up and down relative to the horizon as I changed my bank angle to move up and down. **The Altitude Stabilized target should be used for the High Fidelity task.**

Continued

6. RECOMMENDATIONS (in order of priority)

1. The Altitude Stabilized target should be used for the High Fidelity task.
2. For the Sensitive Stick configuration, increase pitch stick gain to 800.
3. For the Time Delay configuration, the pitch delay should be 200 milliseconds and the roll delay should be 60 milliseconds.
4. Investigate the apparent lack of trim authority during 3 g turns.
5. Aileron rolls to investigate PDS delays should be repeated with a better horizon.

COMPLETED BY	SIGNATURE	DATE
KEVIN T. CHRISTENSEN, Major, USAF	Kevin T Christensen	18 Mar 99

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5. RESULTS OF TESTS *(Continued from front)*

Tracking of the Low Fidelity target with the Baseline configuration resulted in desired performance. The default gain for this task appears to be about right. Based on HQ results against the High and Low Fidelity targets, I thought that the Baseline configuration was somewhere between Level 1 and 2. With learning curve, the evaluation pilots should be able to get desired performance after a few runs.

During the first Phase3 run with the sensitive stick, I was almost able to get desired performance. The default stick gain was 600 both in pitch and roll. On the next pass, after increasing stick gain to 800, longitudinal HQ were degraded to between Level 2 and 3. **For the Sensitive Stick configuration, increase pitch stick gain to 800.**

During the first pass with the Time Delay, the roll axis delay was very objectionable, but the longitudinal delay did not seem to be as much of a problem. We tried to cut the roll delay in half, from 120 to 60 milliseconds, and increase the pitch delay from 120 to 200 milliseconds. On the subsequent run, however, the delays appeared to be swapped. After trouble shooting thins problem, we tried to reverse the delay and seemed to get the desired results. The final delays gave borderline Level 2/3 aircraft. **For the Time Delay configuration, the pitch delay should be 200 milliseconds and the roll delay should be 60 milliseconds.**

During the 3 g pitch frequency sweeps, I tried to trim the jet at 3 g's. Even after running the trim for several seconds, I still had to hold aft stick pressure to hold 3g''. We didn't have the gas to investigate this any further. **Investigate the apparent lack of trim authority during 3 g turns.**

Before starting the aileron rolls, the PDS horizon was about 50 mils above the actual horizon. This was a very rough order estimate since the actual horizon was not very distinct. A full deflection aileron roll caused the end of the horizon line to move to about 60 mils above the actual horizon. With a 1 frame delay in the PDS, I noticed the PDS horizon line lagged by even more. I guessed it was about 70 mils above the horizon. **Aileron rolls to investigate PDS delays should be repeated with a better horizon.**

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
VISTA NF-16	86-0048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE TRACK / VISTA #444	Flight #2 – Config Verification	18 Mar 99
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
Williams	7,600	M94C1400
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
Hutchinson		35 BKN, tops >100, vis UNR
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1010L / 1.1	Ctrline Tank	250/25G35
M. TARGET ACFT / SERIAL NO	**N. TARGET CREW**	**O. TARGET TO TIME / SORTIE TIME**
N/A	N/A	N/A

4. PURPOSE OF FLIGHT / TEST POINTS

4.1. Evaluate the HAVE TRACK Baseline configuration against a Hi-Fidelity HUD Tracking task during HQDT.
4.2. Evaluate the HAVE TRACK Baseline configuration against a Hi-Fidelity HUD Tracking task during repeated phase 3 tasks.
4.3. Evaluate the HAVE TRACK high stick sensitivity configuration against a Hi-Fidelity HUD Tracking task during HQDT.
4.4. Evaluate the HAVE TRACK high stick sensitivity configuration against a Hi-Fidelity HUD Tracking task during repeated phase 3 tasks.
4.5. Evaluate the HAVE TRACK time delay configuration against a Hi-Fidelity HUD Tracking task during HQDT.
4.6. Evaluate the HAVE TRACK time delay configuration against a Hi-Fidelity HUD Tracking task during repeated phase 3 tasks
4.7. Conduct 1g PTI step inputs at the test condition (0.75 Mach, 15K PA) for each configuration.
4.8. Conduct 3g manual frequency sweeps at the test condition (0.75 Mach, 15K PA) for each configuration.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

5.1 OVERALL: Objectives 4.1 through 4.6 were met. Objective 4.3 was accomplished but only 10 seconds of data was acquired before a VSS safety trip occurred. Objective 4.7 was only partially met - only a frequency sweep for the baseline configuration was accomplished, and subsequent data analysis showed this had limited low frequency content. For objective 4.8, only PTIs for the baseline and the sensitive stick configurations were accomplished before RTB for fuel. For details of the flight test program, reference the HAVE TRACK test plan. For details of the HUD and configuration parameters, reference the AFSC Form 5314, VISTA Flt#443.

5.2 TEST CONDITIONS: Altimeter was set to 29.92 for all test points. All handling qualities tasks were accomplished with feet on the floor. For HQDT evaluations, a firm grip on the stick was used with the right arm not braced against the aircraft or the pilot's leg. The pilot's kneepad was placed on the pilot's left leg to keep his right arm unencumbered. Initial error prior to starting HQDT was less than 5 mils in the pitch axis alone. Only pitch axis HQDT was attempted - roll HQDT was not attempted. For phase 3 evaluations, there were no restrictions on techniques to produce the best performance. The task objective was flown to maximize target time in the adequate/desired circles. No attempt was made to limit minor excursions or bobbles outside the adequate/desired criteria. After each configuration change and before HQDT, a phase one evaluation of the aircraft's time delay, predictability, undesired motions, sensitivity, and control harmony for the pitch and roll axes were evaluated to verify the configuration and to buildup prior to HQDT evaluations.

Continued

6. RECOMMENDATIONS (in order of priority)

1. **Recommend prior project aircraft training to eliminate the learning curve for lateral offsets to highlight the pitch axis problem**
2. **Recommend repeated tasks be limited to 4 repetitions to limit the effects of fatigue on task performance.**

COMPLETED BY	SIGNATURE	DATE
TIM WILLIAMS, CAPT, USAF	Timothy L Williams	18 Mar 99

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5.3 TEST RESULTS: The following table summarizes the test results of the flight. A CHR and PIOR was assigned immediately after each maneuver. Video review indicates post flight analysis of performance, which in some cases, changed some ratings.

Rec#	Fuel	CONFIG	PH 2 or 3	PIOR	CHR	VIDEO PERF	COMMENTS
2	6.3	Baseline	2	<4	x	x	No adverse oscillations
3	6.0	Baseline	3	3	6	Adeq-	Lateral solution hard to determine
4	5.8	Baseline	3	3	6	Adeq-	Roll control detracted from pitch ctrl
5	5.7	Baseline	3	3	5	Adeq	Lateral offset, quicker correction, pitch bobl
6	5.4	Baseline	3	3	7	Adeq-	Lateral oscillations left-right-left
8	5.2	Sens Stick	2	5	x	x	
9	4.9	Sens Stick	3	5	8	<Adeq	Quick gross acquisition, +/- 25 mil pitch osc
10	4.8	Sens Stick	3	5	7	Adeq	Lateral osc (no worse than baseline)
12	4.7	Sens Stick	3	5	7	Adeq	Started to use knee to brace arm, dampn osc
13	4.6	Sens Stick	3	5	7	Adeq-	Lateral osc
14	4.5	Sens Stick	3	5	7	Adeq-	Lateral osc
15	4.3	Time Delay	2	4	x	x	Bounded osc, slow frequency
16	4.0	Time Delay	3	4	6	Adeq	Less pitch bobl than sens stick
17	3.8	Time Delay	3	4	7	Adeq-	Lateral correction unpredictbl
18	3.7	Time Delay	3	4	6	Adeq	Lateral oscillations
19	3.6	Time Delay	3	4	8	<Adeq	Lateral oscillations
20	3.5	Time Delay	3	4	6	Adeq	Potential for PIO if bounded ctrl is attempted

5.3.1 BASELINE CONFIGURATION COMMENTS: Phase 1 evaluation showed a predictable, fast pitch response with about 2 overshoots. Stick force was about 10 lb/g. The g onset rate was also fairly quick. The was almost imperceptible time delay in pitch response and on the HUD. Roll control was light but harmony between the pitch and roll was good. There was minmal adverse/proverse yaw. Rudder inputs highlighted a very responsive deadbeat yaw control and heavy dihedral effect. For HQDT, larger inputs did cause larger error outputs but there was no tendency to diverge. For the phase 3 evaluation, 4 events were conducted. Overall, the lateral offsets and roll control inputs largely determined the adequate/desired performance. This detracted from the pitch control required to control the aircraft. In other words, large lateral offsets tended to be accompanied with large pitch oscillations. Although the roll control increased the pilot's workload, it wasn't intended to be the primary emphasis of the project. **Recommend prior project aircraft training to eliminate the learning curve for lateral offsets to highlight the pitch axis problem.** The phase 3 events could be separated into a gross acquisition task and a fine tracking task. Approximately 4.5 to 5 gs were used to gross acquisition the target. Quicker pulls tended to result in larger lateral offsets which tended to about 50 mils. Acquisition into the adequate criteria took between 2 to 3 seconds for pitch and another 3 to 5 seconds for the roll axis. Learning curve affected the pitch axis mostly, as there were no bank angle guidance cues to capture the altitude stabilized target. For fine tracking, there tended to be small oscillations in pitch (+/-10 mils) and roll (+/-20 mils). Learning curve again tended to help the pitch axis mostly as the oscillations decreased from task to task. For the first task, it took 2.5 seconds to attain adequate performance, but pitch oscillations were +/- 10 mils. Lateral oscillations were greater than 10 mils. After the reversal, adequate performance was captured in 3 seconds. Lateral oscillations were outside the adequate performance criteria. As the lateral solution was attained pitch oscillations decreased down to the desired level. On the second task, a 4g pull took 3 seconds to attain adequate performance. After the reversal, 3 seconds was required to attain adequate performance. Pitch bobble was reduced, but lateral excursions went outside the adequate criteria. For the third task, the pilot was caught off guard initially, but adequate performance was obtained in 4 seconds. Laterally excursions went well out of the adequate criteria. Desired performance was attained within 2 seconds prior to the reversal. After the reversal, adequate performance was maintained for a solid 10 seconds. The lateral problem was largely solved, but +/-7 mil oscillations were still present. Learning curve showed quicker correction of lateral errors. For the fourth task, adequate performance was obtained in 3 seconds and desired performance in 7 seconds. After the reversal, large lateral excursions both left and right resulted in less than adequate performance. This highlighted the unpredictability of the lateral axis and the potential for PIO in the lateral axis when the pilot is pressed against the clock.

5.3.2 SENSITIVE STICK CONFIGURATION COMMENTS: Phase 1 evaluation showed a much lighter stick in both pitch and roll. The pitch axis was "twitchy" with undesirable motion when the trim button was clicked. The roll axis showed some roll ratcheting. Control harmony between the two axes was good. Pitch rate was very rapid but predictable. For HQDT, the pitch response was very divergent with about 6 reversals before a safety trip occurred. For the phase 3 evaluation, five events were conducted. Overall, there were much larger pitch oscillations than the baseline configuration. Lateral oscillations were the same as the baseline configuration. Gross acquisition was much faster but fine tracking was worse than the baseline configuration. By bracing the pilot's arm against his leg, pitch oscillations were reduced. For the first event, pitch capture occurred in 2 seconds, but pitch oscillations were +/- 25 mils. After the reversal, a 5.5 g pull captured the target in less than 2 seconds, but pitch oscillations made fine tracking to the adequate level impossible. On the second event, capture to the adequate level occurred in 2 seconds and pitch oscillations were reduced to +/-10 mils. After the reversal, a 5 g pull captured the target in 2-3 seconds, but lateral oscillations of +/- 25 mils made adequate performance barely possible. The third event caught the pilot off guard, but with a 5 g pull, the target was captured in 1 sec. Adequate performance was maintained for the next 5 seconds until lateral excursions exceeded 10 mils. After the reversal, bracing the pilot's right arm against his leg reduced pitch oscillations to the desired level. Adequate performance was maintained and desired performance might have been obtained given a longer run. For the fourth task, gross acquisition was accomplished in 2 seconds, but lateral excursions made adequate performance difficult. Desired performance was maintained for 2 seconds prior to the reversal. After the reversal, the lateral excursions were not controlled until the last 10 seconds. Overall, adequate performance was barely obtained. For the fifth task, a 4 g pull captured the task in 2 seconds. Lateral oscillations occurred before and after the reversal that made performance marginally adequate. Larger pitch oscillations accompanied the lateral excursions. This task highlighted the effects of fatigue on performance. **Recommend repeated tasks be limited to 4 repetitions to limit the effects of fatigue on task performance.** Otherwise the pilot should take a minimum break between events.

5.3.3 TIME DELAY CONFIGURATION COMMENTS: Phase one evaluation showed a very noticeable time delay in both the pitch and roll axes. The delay in the roll axis seemed to be less than the pitch axis. Stick forces were the same as the baseline configuraton. Pitch captures were fairly predictable as long as an open loop control method was applied. For HQDT, step inputs were applied with no effort to change the level of the input once it was applied. This resulted in a bounded oscillation with 1/2 stick level inputs applied. The response was at a much lower frequency than the baseline or sensitive stick configurations. Some asymmetric errors occurred as the stick force for the 3g neutral point was estimated. Typically these asymmtric errors favored the stick forward or direction of trim. As for the phase 3 events, the pitch was relatively predictable with gross acquisition similar to the baseline configuration. For fine tracking, there were oscillations (+/- 10 mils) that were difficult to dampen out. Trying to maintain the oscillations within a certain bound resulted in a PIO. Using an open loop control method, it was fairly easy to control the average of these oscillations. The lateral or roll control was another story. The roll was very unpredictable. Lateral corrections took four or more overshoots to correct the lateral offset. Making small corrections in the lateral axis caused a roll PIO. On the first event, adequate performance was captured in 3 seconds for both before and after the reversal. Oscillations in pitch and roll made desired performance unattainable. For the second event, less than adequate performance was obtained on the first 10 seconds, with adequate performance barely obtainable overall due to light oscillations in both pitch and roll. For the third event, adequate performance was attained for most of the fine tracking. The lateral axis caused less than desired performance overall. The fourth event saw worse performance due to lateral offsets. Attempting to correct these offsets quickly caused roll oscillations. The last event saw improved performance with less roll oscillations as the lateral offsets were reduced. Again, trying to limit the pitch oscillations to the desired criteria caused a pitch PIO.

5.4 PTI, FREQUENCY SWEEPS: A pitch step PTI was conducted for the baseline and sensitive stick configurations. A manual frequency sweep was only conducted on the baseline configuration before RTB for fuel. Subsequent data analysis was showed minimal low frequency content for the manual frequency sweep. This data could be obtained on other HAVE TRACK missions.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE VISTA NF-16	2. SERIAL NUMBER 86-0048	

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO HAVE TRACK / VISTA #445	B. FLIGHT NO / DATA POINT Flight #3 –High Fidelity HUD	C. DATE 18 Mar 99
D. FRONT COCKPIT *(Left Seat)* Cassidy	E. FUEL LOAD 7,600	F. JON M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)* Peer	H. START UP GR WT / CG	I. WEATHER 10 OVC, 4
J. TO TIME / SORTIE TIME 1433L / 1.0	K. CONFIGURATION / LOADING Ctrline Tank	L. SURFACE CONDITIONS Temp 3C, 230/20G30, Alt 29.81
M. TARGET ACFT / SERIAL NO N/A	N. TARGET CREW N/A	O. TARGET TO TIME / SORTIE TIME N/A

4. PURPOSE OF FLIGHT / TEST POINTS

1. Perform Phase 1,2,3 maneuvering against the high fidelity HUD target. Perform one each of a Phase 1 warm up and Phase 2 HQDT. Perform 5 Phase 3 operational handling tracking tasks.
2. Perform PTI step inputs and manual frequency sweeps for each flight control configuration. Accomplish the manual frequency sweeps in a 3G turn with G varying from 2-4.
3. Perform an additional set of phase 2 HQDT maneuvers against each configuration.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

All maneuvers were accomplished except the second round of HQDT. Only 4 sets of the tracking task were accomplished against each configuration. All maneuvers were accomplished at 15,000 ft and .75 M. Maneuvers were accomplished with no rudder inputs. Manual frequency sweeps were accomplished trimmed for 2.4 Gs to standardize with the previous flight. The flight was terminated prior to finishing all the test points due to the high fuel bingo for an IFR recovery.

The baseline configuration was easy to fly. It was slightly more sensitive than expected but this was not objectionable. It was stable in both 1G and 3G flight. A slight amount of unwanted motion was noted during HQDT. In general, adequate performance was achieved during the tracking tasks. Roll control required the most compensation. Workload was moderate to high and was driven by lateral control difficulties more than pitch difficulties. No learning curve was noted. Slight fatigue was noted at the end of the last tracking task.

The sensitive stick configuration was twitchy and difficult to fly at 1G. This configuration was noticeably more sensitive in pitch and slightly more sensitive in roll than the baseline configuration. The sensitivity was objectionable in 1G flight. More unwanted motion was noted during HQDT than the baseline but there was no tendency to oscillate. Gross acquisition was easier for the sensitive configuration and about the same as baseline for fine tracking. This tracking task got much easier over the 4 maneuvers. This may have been a result of the ease of gross acquisition or from the practice on the baseline configuration. In general, performance was adequate but closer to desired than the baseline configuration. Workload overall was slightly less. No fatigue was noted. The learning curve was significant.

The time delay configuration was barely controllable. Any control input at 1G would result in a pitch oscillation. Pitch control inputs had to be very slow and deliberate to stabilize on a pitch capture. The first attempt at HQDT resulted in a safety trip in pitch on the first pitch reversal. The second attempt at HQDT was successful and resulted in an unbounded oscillation as soon as tight control was attempted. The tracking task initially was uncontrollable. The task became controllable with practice. This configuration was extremely frustrating. Target vibrations were noted in this configuration.

The manual frequency sweeps were difficult to accomplish accurately at 3 Gs. Initial G may have been jumpy during the first cycle. Follow on cycles were smoother but G accuracy was 3G±1.5G. Trim helped. Practice helped.

6. RECOMMENDATIONS (in order of priority)

None

COMPLETED BY EDWARD V. CASSIDY, Captain, USAF	SIGNATURE Edward V. Cassidy	DATE 19 Mar 99

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5. RESULTS OF TESTS *(Continued from front)*

The following summarizes HQRs and PIORs for each run:

Config	Target	HQDT PIOR	Ph 3 PIOR	Ph 3 HQR
Baseline	Hi Fi	2		
Baseline	Hi Fi		2	5
Baseline	Hi Fi		2	6
Baseline	Hi Fi		2	6
Baseline	Hi Fi		2	6
Sensitive	Hi Fi	3		
Sensitive	Hi Fi		3	8
Sensitive	Hi Fi		3	8
Sensitive	Hi Fi		3	6
Sensitive	Hi Fi		2	5
Time Delay	Hi Fi	6		
Time Delay	Hi Fi		6	10
Time Delay	Hi Fi		6	10
Time Delay	Hi Fi		4	9
Time Delay	Hi Fi		4	9

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
VISTA NF-16	86-0048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE TRACK / VISTA #446	Flight #4 – HAVE TRACK	19 Mar 99
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
Williams	7,600	M94C1400
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
Hutchinson		35 BKN, tops 50, vis UNR
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1005L / 1.1	Ctrline Tank	250/25G35
M. TARGET ACFT / SERIAL NO	**N. TARGET CREW**	**O. TARGET TO TIME / SORTIE TIME**
T-38 / 558	Asher/Christenson	1005L/1.1

4. PURPOSE OF FLIGHT / TEST POINTS

4.1. Evaluate the HAVE TRACK Baseline configuration against a T-38 Tracking task during HQDT.
4.2. Evaluate the HAVE TRACK Baseline configuration against a T-38 Tracking task during repeated phase 3 tasks.
4.3. Evaluate the HAVE TRACK high stick sensitivity configuration against a T-38 Tracking task during HQDT.
4.4. Evaluate the HAVE TRACK high stick sensitivity configuration against a T-38 Tracking task during repeated phase 3 tasks.
4.5. Evaluate the HAVE TRACK time delay configuration against a T-38 Tracking task during HQDT.
4.6. Evaluate the HAVE TRACK time delay configuration against a T-38 Tracking task during repeated phase 3 tasks
4.7. Conduct 1g PTI step inputs at the test condition (0.75 Mach, 15K PA) for each configuration.
4.8. Conduct 3g manual frequency sweeps at the test condition (0.75 Mach, 15K PA) for each configuration.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

5.1 OVERALL: Objectives 4.1 through 4.6 were met. For objectives 4.7 and 4.8, only PTIs and manual frequency sweeps for the added time delay and sensitive stick configurations were accomplished before RTB for fuel. For details of the flight test program, reference the HAVE TRACK test plan. For details of the HUD and configuration parameters, reference the AFSC Form 5314, VISTA Flt#443.

5.2 TEST CONDITIONS: Altimeter was set to 29.92 for all test points. All handling qualities tasks were accomplished with feet on the floor. For HQDT evaluations, a firm grip on the stick was used with the right arm not braced against the aircraft or the pilot's leg. The pilot's kneepad was placed on the pilot's left leg to keep his right arm unencumbered. Initial error prior to starting HQDT was less than 5 mils in the pitch axis alone. Only pitch axis HQDT was attempted -- roll HQDT was not attempted. For phase 3 evaluations, there were no restrictions on techniques to produce the best performance. The intersection of the trailing edge of the T-38's wing with its longitudinal axis was used as its center target. The task objective was flown to maximize target time in the adequate/desired circles. No attempt was made to limit minor excursions or bobbles outside the adequate/desired criteria. After each configuration change and before HQDT, a phase one evaluation of the aircraft's time delay, predictability, undesired motions, sensitivity, and control harmony for the pitch and roll axes were evaluated to verify the configuration and to buildup prior to HQDT evaluations.

Continued

6. RECOMMENDATIONS (in order of priority)

1. **Recommend camera shots be conducted at a distance no greater than 2000'.**
2. **The HUD task should be modeled off T-38 flight data.**
3. **Recommend prior project aircraft training to eliminate the learning curve for lateral offsets to highlight the pitch axis problem.**

COMPLETED BY	SIGNATURE	DATE
TIM WILLIAMS, CAPT, USAF	Timothy L Williams	19 Mar 99

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5.3 TEST RESULTS: A camera shot was conducted to verify the alignment of the HUD camera. The target aircraft was centered in the standby reticle at 6000 feet in trail. It was fairly difficult to correct lateral offsets of the target due to the pendulum effect of the reticle. Lateral oscillations were +/- 5 mils, and this highlighted the lateral correction problems experienced later during the Phase 2 and 3 tracking tasks. Theoretically the pendulum effects would be greater for the 1 g case than the 3g case, where the flight path is closer to the standby reticle. Video review demonstrated that at 6000' the target was not visible. **Recommend camera shots be conducted at a distance no greater than 2000'.** For video analysis, the calibration determined in flight #445 was used. The following table summarizes the test results of the flight. A CHR and PIOR was assigned immediately after each maneuver. Post flight video analysis of performance changed some ratings.

Rec#	Fuel	CONFIG	PH 2 or 3	PIOR	CHR	VIDEO PERF	COMMENTS
1	6.2	Baseline	2	<4	x		lateral offset errors
2	6.1	Baseline	3	3	6	Adeq-	lateral offset errors took 5 sec to correct
3	5.8	Baseline	3	3	6	Adeq	lateral offset, slightly better perf
4	5.6	Baseline	3	3	5	Adeq+	lateral offsets corrected in 2-3 sec
5	5.2	Sens. Stick	2	5	x		Safety Trip, divergent
6	4.9	Sens. Stick	3	5	6	Adeq	lateral offset after reversal
7	4.7	Sens. Stick	3	5	5	Adeq	gross acq worse, better fine tracking
8	4.5	Sens. Stick	3	5	4	Desired	lateral offset initially, desired last 15 sec
9	4.2	Time Delay	2	4	x		Safety Trip, slow freq
10	4.0	Time Delay	3	3	7	Adeq-	lateral offset corrected w/I 8 sec
11	3.9	Time Delay	3	3	6	Adeq	lateral offset better, pitch oscil.
12	3.6	Time Delay	3	3	5	Adeq+	target early terminate
13	3.5	Time Delay	3	3	8	Adeq-	+/- 10 mil bobble, fatigue, worse perf w/ inc. workload

5.3.1 BASELINE CONFIGURATION COMMENTS: Phase 1 maneuvering revealed 2 overshoots for step inputs and a period of less than 1 second. Stick force per g was less than 15 lb/g. Very small delay was noticed in pitch response. Roll response was similar with less force and less delay. Control harmony was good overall. For HQDT, larger inputs caused larger errors, but there were no tendencies to diverge. The need to solve the lateral offset problem early was identified. This required an open loop 2-step method to correct lateral offsets. Three phase 3 events were accomplished. Performance improved through the three events. Task performance can be broken into gross acquisition and fine tracking. Gross acquisition tended to show about one pitch overshoot and 50 mil lateral offset before stabilization. Until the T-38 stabilized on its turn rate, the cues for bank angle were somewhat uncertain. Once the lateral offset was solved into the adequate circle, control could be concentrated on the pitch axis. This fine tracking showed about +/-5 mils in pitch oscillations. No trim was used, but the pilot's arm was braced against his leg. For the first event, adequate performance was attained in 8 seconds initially, and within 5 seconds after the reversal. For the second event, adequate performance was attained in 7 seconds initially, and in 5 seconds after the reversal. Desired performance was attained for the last 10 seconds. For the third event, adequate performance was attained within 2 seconds and desired within 8 seconds. After the reversal, adequate performance was attained in 5 seconds and desired performance in 7 seconds. The workload went down as the target was stabilized in the desired circle. If the task were continued for more than 20 seconds, better average performance would be obtained. Learning curve was primarily focused in the lateral offset or bank angle control.

5.3.2 SENSITIVE STICK CONFIGURATION COMMENTS: Phase 1 maneuvers showed a very "twitchy" aircraft in the 1 g condition. Friction and breakout was reduced, and caused undesirable motions as the trim button was clicked. There were still two overshoots for the pitch axis step input. The roll axis was also very sensitive. The control harmony was good but caused some minor roll ratcheting. During HQDT, the roll axis caused lateral oscillations to acquire the target. When initiating HQDT on the pitch axis, there was a definite tendency to diverge. The pilot's gain's

had to be reduced to maintain a set error output. The HQDT was continued to achieve 10-20 good reversals for data analysis purposes before a safety trip occurred. For the phase 3 tasks, the learning curve from the previous configuration influenced the lateral axis acquisition problem. Again, the pilot braced his arm against his leg to reduce oscillations in both the pitch and lateral axis. The pilot had to exit the loop to minimize pitch oscillations. For the first event, large overshoots in pitch and a large lateral offset occurred but were stabilized within the adequate criteria in 2 seconds. After the reversal, an overbank caused a lateral offset that wasn't stabilized into the adequate criteria for 7 seconds. In 10 seconds, desired performance was obtained for the last 10 seconds. Lateral oscillations were minimal, but pitch oscillations were +/- 5 mils. These could only be achieved by bracing the pilot's arm against his leg and backing out of the loop. For the second event, adequate performance was obtained in 2 seconds initially, but some +/- 10 mil pitch oscillations made desired performance impossible. After the reversal, a large overbank caused a 50 mil lateral offset that resulted in adequate performance for the last 13 seconds. While correcting the lateral offset, pitch oscillations were +/- 10 mils. Desired performance was obtained in 10 seconds with smaller +/- 3 mil oscillations. There was worse performance on the second event overall mostly due to large lateral offsets, but the final pitch oscillations were reduced. Workload on the second event also increased. The workload for correcting the lateral offset reduced the pilot's ability to compensate for the pitch axis. For the third task, a 40 mil left lateral error required 5 sec to correct to adequate performance and 8 seconds to correct to desired performance. After the reversal, desired performance was achieved for the last 15 sec. Near the end of this 15 seconds, the workload was reduced as the solution to maintain desired performance was identified. Still, there was great propensity for PIO in both the pitch and roll axis.

5.3.3 TIME DELAY CONFIGURATION COMMENTS: Phase 1 evaluation highlighted a very noticeable delay in both pitch and roll, although the delay in the roll was significantly less than the pitch axis. Compared to the sensitive stick, there was minimal twitchiness in the response. Relatively good harmony existed between the pitch and roll axes. For HQDT, it was easier to relax the aft stick force than to increase aft stick force. Thus, the stick movement was quicker in the forward direction than the aft direction. This caused some asymmetric error response. With larger stick inputs the asymmetric error was reduced. Error response was at a lower frequency than the baseline, and it did not have a tendency to diverge. Larger outputs occurred with larger inputs, and a potential bounded oscillation was present before the a safety trip occurred. For phase 3 evaluations, 4 events were conducted. For the first event, adequate performance was obtained within 2 seconds and desired within 8 seconds. After the reversal, adequate performance was obtained within 5 seconds. It was difficult to achieve a steady lateral solution, and this might have led to +/- 10 mil pitch oscillation. For the second event, adequate performance was obtained in 2 seconds and desired within 5 seconds. After the reversal, adequate performance was obtained within 5 seconds but due to low frequency roll oscillations, desired performance could not be consistently achieved. Pitch oscillations were +/- 10 mils. There was no "preciseness" in the aircraft response. The relative ease of gross acquisition was overshadowed by the lack of precise fine tracking. For the third event, adequate performance was achieved initially in 2 seconds and desired in 5 seconds with some minor oscillations outside the desired criteria. After the reversal, a large pitch overshoot caused adequate acquisition within 4 seconds. Due to a target early terminate, fine tracking was not completely evaluated. On the fourth event, adequate performance was achieved in 2 seconds, but wake turbulence was caused a 40 mil lateral offset. Adequate performance was reacquired for the last 2 seconds before the reversal. After the reversal, it took 7 seconds to attain adequate performance with minor oscillations that fell out of the adequate criteria. +/- 10 mil oscillations occurred in both pitch and roll, but at different frequencies. This could be due to fatigue and frustration associated with attaining a fine tracking solution. Overall, this performance was worse with a much higher workload than the previous event. The time delay configuration had major unpredictability problems. Open loop inputs to compensate were not always met with success, and dynamic, precise adjustments were not possible

5.3.4 COMPARISON BETWEEN T-38 AND HI-FIDELITY HUD TASK: The T-38's final turn rate was very similar to the Hi-Fidelity HUD task. The turn rate buildup for the T-38 took approximately 5 seconds compared to the Hi-fidelity HUD target's 2 seconds. **The HUD task should be modeled off T-38 flight data.** This caused earlier gross acquisition on the T-38 but also oscillations in pitch and an unpredictable lateral solution until the T-38 stabilized on turn rate. The perspective of the T-38 might have given greater acquisition cues than the Hi-fidelity HUD task. Training in solving the lateral solution would have uncovered greater differences in the pitch axis among the different configurations. **Recommend prior project aircraft training to eliminate the learning curve for lateral offsets to highlight the pitch axis problem.** Simulator training gave little added benefit in training for the T-38 and Hi-fidelity HUD tasks.

5.4 PTI, FREQUENCY SWEEPS: A PTI step for the stick-sensitive and time-delay configuration were accomplished. A manual frequency sweep for the sensitive stick and time-delay configuration were accomplished.

5.5 POST-FLIGHT VIDEO ANALYSIS:

Event	Total Time	W/I 25 Mil	W/I 10 Mil	W/I 5 Mil
Baseline #1	31	24 (77.4%)	17(54.8%)	9 (29.0%)
Baseline #2	31	24 (77.4%)	17 (54.8%)	14 (45.2%)
Baseline #3	30	27 (90.0%)	22 (73.3%)	15 (50.0%)
Sens Stick #1	31	24 (77.4%)	19 (61.2%)	13 (41.9%)
Sens Stick #2	31	25 (80.6%)	17 (54.8%)	10 (32.2%)
Sens Stick #3	33	31 (94.0%)	27 (81.8%)	18 (54.5%)
Time Delay#1	34	31 (91.1%)	23 (67.6%)	9 (26.5%)
Time Delay#2	33	30 (90.9%)	23 (69.7%)	9 (27.2%)
Time Delay#3	25	22 (88.0%)	15 (60.0%)	6 (24.0%)
Time Delay#4	38	36 (94.7%)	27 (71.1%)	11 (28.9%)

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
VISTA NF-16	86-0048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINT	C. DATE
HAVE TRACK / VISTA #447	Flight #5 – T-38 target	19 Mar 99
D. FRONT COCKPIT *(Left Seat)*	**E. FUEL LOAD**	**F. JON**
Cassidy	7,600	M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)*	**H. START UP GR WT / CG**	**I. WEATHER**
Peer		34OVC, 10
J. TO TIME / SORTIE TIME	**K. CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1435L / 1.2	Ctrline Tank	Temp 2C, 290/13G18, Alt 30.19
M. TARGET ACFT / SERIAL NO	**N. TARGET CREW**	**O. TARGET TO TIME / SORTIE TIME**
T-38/1558	Christensen/Behnken	1435/1.2

4. PURPOSE OF FLIGHT / TEST POINTS

1. Perform Phase 1,2,3 maneuvering against a T-38 target. Perform one each of a Phase 1 warm up and Phase 2 HQDT. Perform 3 sets of Phase 3 operational handling tracking tasks.
2. Perform an additional set of phase 2 HQDT maneuvers against the T-38 target for each configuration.
3. Perform step PTIs for each configuration.
4. Perform an additional set of phase 2 HQDT maneuvers against the high fidelity HUD target for each configuration.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

All maneuvers were completed. All maneuvers were accomplished at 15,000 ft and .75 M with no rudder inputs. A camera check was accomplished. The programmable symbology was off significantly but was only a factor for tape review on the ground. The correction required moving the symbology about 5 mils left and 20 mils up.

In general, all maneuvers against the T-38 were easier than the high fidelity task. The baseline configuration was comfortable to fly at both 1G and 3Gs. During the 3G HQDT task, no unwanted motions were noted. Oscillations would converge very quickly on to the target. Large and small amplitudes would converge. Performance improved during the phase 3 tracking. T-38 tracking was easier than the high fidelity target especially during the target reversals. Desired performance was achieved on the last event. Wake turbulence was a factor during the first turn on the second tracking task. Most effort was spent controlling roll. Pendulum effect was noted. Fatigue was not a factor. The tasks became easier as I proceeding through the events. Learning was especially apparent in compensating for pendulum effect during the target reversals.

The sensitive stick configuration was twitchy and difficult to fly at 1G. The sensitive stick was easier to fly than the baseline at 3 Gs. HQDT resulted in slight unwanted motions. Oscillations would converge on the target but not as fast as the baseline configuration. This was true for both large and small amplitude HQDT. Gross acquisition during phase 3 was easier and quicker to accomplish. Compensation was required to avoid overshooting the target. Performance was rated adequate but close to desired on the first and second tracking tasks. Post flight tape review revealed that desired performance was achieved during the first set of phase 3 tracking. Desired performance was achieved on the third tracking task. Tracking on sets 1 and 3 were easier because the target was slightly closer. The aircraft seemed to do exactly what I wanted with some slight unwanted motions in roll. The tasks became easier. This configuration may have been easier from the training on the previous configuration. No fatigue was noted.

The time delay configuration was the most difficult of the 3 configurations but still much easier against the T-38 than the high fidelity HUD target. Pitch control was uncomfortable. No unwanted motions were noted in roll. Divergent oscillations in pitch were noted during HQDT. Only small oscillations were attempted. I noticed a huge improvement in performance in the tracking task using the T-38 as a target as opposed to the high fidelity task with this configuration. Initial target acquisition and tracking a reversing target were very difficult. Tracking was easy against a non-maneuvering target. Adequate performance was achieved. Unwanted motions in pitch hampered task performance. No target vibrations were noted with the radar altimeter turned off.

Continued

6. RECOMMENDATIONS (in order of priority)

None

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EDWARD V. CASSIDY, Captain, USAF	Edward V. Cassidy	20 Mar 99

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5. RESULTS OF TESTS *(Continue on reverse if needed)*

The additional phase 2 HQDT tasks were very fatiguing. Very little difference was noted between the T-38 and the high fidelity targets. Converging oscillations were noted during both baseline HQDT tasks. Oscillations were more pronounced for the sensitive stick but still converged. The time delay configuration resulted in pitch trips on both the T-38 and high fidelity targets. Pitch oscillations were big enough on the high fidelity task that I lost track of the target symbol.

Overall, bad flight control configurations were not so bad against the T-38. Bad flight control configurations were really bad against the HUD target. This may have been a result of learning to compensate from the first to second sortie. Performance is strongly dependent on target range.

The following summarizes HQRs and PIORs for each run:

Config	Target	HQDT PIOR	Ph 3 PIOR	Ph 3 HQR
Baseline	T-38	1		
Baseline	T-38		1	5
Baseline	T-38		1	5
Baseline	T-38		1	3
Sensitive	T-38	2		
Sensitive	T-38		1	5
Sensitive	T-38		2	5
Sensitive	T-38		1	3
Time Delay	T-38	5		
Time Delay	T-38		3	7
Time Delay	T-38		3	6
Time Delay	T-38		3	5
Baseline	T-38	2		
Sensitive	T-38	3		
Time Delay	T-38	5		
Baseline	Hi-Fi	2		
Sensitive	Hi-Fi	3		
Time Delay	Hi-Fi	5		

DAILY INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
NF-16D	86048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINTS	C. DATE
Have Track / VISTA #448	Flight #6 - Hi-Fidelity HUD target	20 March 1999
D. FRONT COCKPIT (Left Seat)	**E. FUEL LOAD**	**F. JON**
Capt Troy Asher	7500 lb.	M96J0200
G. REAR COCKPIT (Right Seat)	**H. START UP GR WT / CG**	**I. WEATHER**
Mr. Karl Hutchinson		Clear, Visibility 6 nm
J. TO TIME / SORTIE TIME	**K CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
0829 / 1.1	Centerline tank	Wind 2506, -1°C, 30.28, Rwy dry
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
n/a	n/a	n/a

4. PURPOSE OF FLIGHT

To evaluate the VISTA's handling qualities when configured with the three HAVE TRACK flight control configurations by tracking a *hi-fidelity HUD generated target*. Evaluate handling qualities via pilot comments and ratings.

The following maneuvers were flown in each flight control configuration (baseline, sensitive stick, and added time delay) using the virtual HUD target:

- Open loop and semi-closed loop maneuvers (stick raps, step inputs, pitch, bank and heading captures)
- Tracking the virtual target using the Handling Qualities During Tracking (HQDT) technique with the target flying a predetermined profile
- Tracking the virtual target in an "operationally representative" manner (maintaining the smallest error possible) with the target flying a predetermined profile.
- Operational tracking task repeated 3 times
- Fuel permitting, HQDT repeated 1 time in each flight control configuration
- PTI step inputs at the test condition (0.75 Mach, 15K PA, 1-g) for each configuration
- Manual frequency sweeps at the test condition (0.75 Mach, 15K PA, 3-g) for each configuration

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Overall: All objectives for the flight were met except acquiring data from the PTI step inputs and manual frequency sweeps. The maneuvers were flown, but the data lost due to a tape recording malfunction. The weather was clear with only scattered clouds and the winds were calm. The flight was flown as planned. In general, the virtual target's predetermined flight profile was found to be somewhat different than the T-38's, primarily in the g-onset rates for roll-ins and turn reversals. Also, the hi-fidelity HUD target was significantly larger than the actual T-38 at 2000 feet spacing which was favorable for HQDT, but somewhat unrealistic for phase 1 and phase 3 maneuvers.

Phase 1 Maneuvers: Precise evaluation of an aircraft's handling qualities during phase 1 maneuvers was more difficult without an airborne target (there were no mountain tops or clouds to track this day.) Sensitivities in pitch and roll were not as evident, predictability was harder to assess, pitch and heading captures without a target did not reveal as much, and the aircraft's initial response to stick inputs was not as easy to judge because there was nothing to use for pitch rate comparison. The project did not include a non-maneuvering hi-fidelity HUD target for use in phase 1 maneuvers. **Incorporate an altitude stabilized, non-maneuvering HUD target for phase 1 handling qualities evaluations (R1).** Also, it was immediately evident that the hi-fidelity HUD target was much larger than an actual T-38 sized target at 2000 feet separation. The T-38's wingspan at 2000 feet was approximately 20 mils. Each of the hi-fidelity HUD target's wings were 25 mils, making the entire wingspan of the hi-fidelity target approximately 70 mils. This was helpful during longitudinal HQDT as it gave you a single axis reference to track allowing more isolation of the longitudinal axis. With a point target, concentrating on a single axis would have been more difficult in phase 2 maneuvers. It was not a very realistic representation of an actual target, however. **Use the large wingspan, hi-fidelity target for HQDT maneuvers that concentrate on the longitudinal axis (R2). For more realism, modify the hi-fidelity target to more accurately reflect the size of an actual target at 2000 feet for phase 1 and phase 3 maneuvers (R3).**

(continued)

6. RECOMMENDATIONS

R4. Repeat PTI step inputs and manual frequency sweeps in each flight control configuration with a functioning data recorder

R1. Incorporate an altitude stabilized, non-maneuvering HUD target for phase 1 handling qualities evaluations

R2. Use the large wingspan, hi-fidelity target for HQDT maneuvers that concentrate on the longitudinal axis

R3. For more realism, modify the hi-fidelity target to more accurately reflect the size of an actual target at 2000 feet for phase 1 and phase 3 maneuvers

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Capt Troy Asher	T A Asher	20 Mar 99

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5. RESULTS OF TESTS *(Continued from front)*

-Baseline configuration: This configuration yielded an aircraft that had a crisp pitch response with little initial delay and that was fairly predictable. Some minor overshoots were present in pitch as well as roll. The roll response was also quick but tended to overshoot desired bank angles somewhat.

-Sensitive stick configuration: The aircraft's pitch response in this configuration was abrupt, jerky and less predictable with 1-2 overshoots of desired pitch angles due to a tendency to over control. Sensitivity was such that simply adding nose up or down trim caused pitch bobbles. The roll response also seemed more sensitive and less predictable.

-Time delay case: The aircraft's pitch response in this configuration seemed initially sluggish and was unpredictable due to numerous overshoots when performing pitch captures. Stick raps revealed what seemed like about ½ second time delay. The roll response also exhibited apparent time delay (initial sluggishness, overshoots) but not as much.

Phase 2 HQDT Maneuvers: Table D1 summarizes the results of HQDT maneuvers in the three configurations. HQDT was performed once in each configuration before completing the phase 3 maneuvers. Once all test points were complete at the end of the sortie, enough fuel remained to reaccomplish one HQDT in each configuration.

- *Baseline configuration:* Oscillations converged as control inputs were increased to near maximum stick deflection. No inherent PIO tendency was noted and pitch response followed control inputs.

-Sensitive stick configuration: Abruptness in pitch response caused unwanted overshoots and over control. This resulted in a bounded PIO that increased in amplitude as the amplitude of the control input increased but divergence in pitch angle or rate was not evident. The PIO could be arrested by quickly lowering pilot bandwidth or by discontinuing the task. G excursions from +3-g to -0.5-g were experienced during this task.

- *Added time delay configuration*: The initial sluggishness in pitch response caused an unconscious additional increase in stick force which resulted in a very abrupt pitch response once the inputs took effect. This had the outcome of causing serious overshoots which required an even larger control input to reverse. The result was an oscillation that diverged in 2-3 overshoots. The only way to stop the PIO was to discontinue the task and recover the aircraft. G excursions from +4.5-g to -1.2-g were experienced.

Phase 3 Operational Tracking Tasks: Table D2 summarizes the pilot ratings given for the various phase 3 tasks. Five tasks were completed in each configuration. At the end of the mission, enough fuel remained to complete one additional phase 3 task in the baseline configuration to assess learning curve effects. Throughout all maneuvers, lateral control was the discriminating factor in task performance. If during initial capture tasks, lateral control overshoots and oscillations were present, this carried through for the remainder of the task and made the difference between desired, adequate or less than adequate performance. Also, learning effects were evident as the sortie progressed with increased performance in most cases and decrease in pilot workload regardless of configuration.

- *Baseline configuration:* Initially the task was difficult and adequate performance was not achieved. There was a common tendency to over-bank during the initial capture of the target which cased a lateral oscillation that was difficult to dampen out. The best performance in all cases was achieved after the roll reversal during the last 10 seconds of the task (steady 3-g turn). Performance increased as successive tasks were accomplished and workload decreased as I "learned" how to better control the roll oscillations. Compensation consisted of matching the target's bank angle first, and only then pulling to center the target longitudinally. Performance was directly related to how well and how quickly I was able stabilize at the target's bank angle. Additionally, a light stick grip was used with my forearm resting on my thigh for stability.

- *Sensitive stick configuration*: The initial capture of the target was noticeably easier with the sensitive stick but once the target was captured, fine tracking was more difficult than the baseline case. Over-banking and lateral oscillation problems were still present, but control of the lateral error seemed easier, was reduced quicker, and was less of a detracting factor. The main problem was over control during fine tracking that caused overshoots and small PIOs mostly in pitch. Compensation again consisted of a light grip on the stick and reduced pilot bandwidth.

- *Added time delay configuration:* This configuration yielded qualities that were basically opposite of the sensitive stick case. The initial pitch capture was harder due to the sluggish feel and pitch PIOs occurred when the pipper finally reached the target. Control of the lateral axis was again the discriminating factor in task performance as it was with the baseline configuration. PIO during fine tracking was not as much of a problem as in the sensitive stick case. Some learning effects were evident, but results were inconsistent due to the poor predictability and possible pilot fatigue - this was near the end of the mission. Compensation consisted of a light grip on the stick, freezing the controls and waiting for inputs to take effect and leading the target in both pitch and roll.

PTI Inputs and Frequency Sweeps: PTI step inputs were flown in all configurations at 15,000 feet PA, 0.75 mach and 1-g. Manual frequency sweeps were also flown in all configurations at 15,000 feet PA, 0.75 mach and 3-g. No data was collected from these maneuvers due to a data recorder malfunction. **Repeat PTI step inputs and manual frequency sweeps in each flight control configuration with a functioning data recorder (R4).** The manual frequency sweep was difficult to perform at 3-g and was substantially easier if the aircraft was trimmed to hold a 3-g turn. Once establishing the 3-g turn, it took 12-15 seconds of steady nose-up trim actuation to fully trim out all stick forces.

Additional Test Point: At the completion of the phase 3 tasks and additional phase 2 tasks, a final phase 3 task was completed in the baseline configuration. This is shown as the last entry in table 2. The purpose of flying this point was to evaluate overall learning effects throughout the mission. As shown in the table, pilot ratings were the same as previous cases. This was due to inability to actually achieve desired performance. Workload did seem to be less than previously experienced.

Table D1
SUMMARY OF PILOT RATINGS FROM
HANDLING QUALITIES DURING TRACKING (HQDT)

Test Point	Record	PIOR	Fuel (lbs)
Baseline 1	2	1	6,600
Baseline 2	28	1	2,700
Sensitive St. 1	9	4	5,500
Sensitive St. 2	29	4	2,500
Time Delay 1	16	5	4,400
Time Delay 2	30	5	2,300

Note: PIOR – pilot-induced oscillation rating

Table D2
SUMMARY OF PILOT RATINGS FROM OPERATIONAL TRACKING

Test Point	Record No.	CHR	PIOR	Fuel (lbs)
Baseline	3	7	3	6,400
Baseline	4	6	3	6,300
Baseline	5	5	2	6,100
Baseline	6	5	2	6,000
Baseline	7	5	2	5,800
Sensitive St.	10	7	4	5,300
Sensitive St.	11	6	3	5,200
Sensitive St.	12	6	3	5,000
Sensitive St.	13	7	4	4,900
Sensitive St.	14	6	3	4,700
Time Delay	17	7	4	4,300
Time Delay	18	6	3	4,200
Time Delay	19	5	2	4,000
Time Delay	20	6	4	3,800
Time Delay	21	7	4	3,700
Baseline	31	5	2	2,200

Notes: 1. CHR – Cooper-Harper rating
2. PIOR – pilot-induced oscillation rating

DAILY INITIAL FLIGHT TEST REPORT	1. AIRCRAFT TYPE NF-16D	2. SERIAL NUMBER 86048
3. CONDITIONS RELATIVE TO TEST		
A. PROJECT / MISSION NO Have Track / VISTA #449	B. FLIGHT NO / DATA POINTS Flight #7 - T-38 Target	C. DATE 20 March 1999
D. FRONT COCKPIT (Left Seat) Capt Troy Asher	E. FUEL LOAD 7500 lb.	F. JON M96J0200
G. REAR COCKPIT (Right Seat) Mr. Jeff Peer	H. START UP GR WT / CG	I. WEATHER Clear, Visibility 10 nm
J. TO TIME / SORTIE TIME 1128 / 1.1	K CONFIGURATION / LOADING Centerline tank	L. SURFACE CONDITIONS Wind 2206, 3°C, 30.28, Rwy dry
M. CHASE ACFT / SERIAL NO T-38 / 1558	N. CHASE CREW Maj Christensen/Capt Behnken	O. CHASE TO TIME / SORTIE TIME 1128/1.2

4. PURPOSE OF FLIGHT

To evaluate the VISTA's handling qualities when configured with the three HAVE TRACK flight control configurations by tracking an *actual aircraft as a target (T-38)*. Evaluate via pilot comments and ratings.

The following maneuvers were planned in each flight control configuration (baseline, sensitive stick, and added time delay) using the T-38 as a target:

- HUD camera checks using the T-38 as a target
- Open loop and semi-closed loop maneuvers (stick raps, step inputs, vertical and horizontal target captures)
- Tracking using the HQDT technique with the T-38 flying a predetermined flight profile
- Tracking in an "operationally representative" manner (maintaining the smallest error possible) with the T-38 flying a predetermined flight profile
- Operationally representative tracking tasks repeated 3 additional times
- Fuel permitting, HQDT repeated 1 additional time

In the baseline flight control configuration, 360° aileron rolls with 0, 1, and 2 frames of time delay added.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Overall: All objectives for the flight were met. The weather was clear with only scattered clouds and the winds were calm. The flight was flown as planned. A 20 bias was found in the HUD camera. Lateral oscillations were found to be the discriminator in task performance. The predetermined T-38 flight profile was found to be a somewhat unrealistic operational maneuver and needed to be modified somewhat. Delays in the flight test HUD at maximum roll rates were quite noticeable.

Execution: Camera checks and phase 1 maneuvers in the baseline configuration were flown enroute to the Misty MOAs. The HUD camera was found to have a bias that showed the reticle approximately 20 mils lower and to the left of the target on the video than it actually was when looking through the HUD in flight. Once in the MOAs, an HQDT maneuver (phase 2) was flown versus the T-38 flying the un-timed tracking task: a 1 second roll-in to a level, 3-g turn to the right for 10 seconds followed by a 2 second unloaded reversal and a level 3-g turn to the left which was maintained until the test aircraft called for termination. Next, 4 phase 3 operational tracking maneuvers were flown in succession in the baseline configuration versus the T-38 flying the timed tracking task, which was the same as the un-timed task except the final 3-g turn to the left was terminated by the target automatically after 20 seconds. Following this, the VISTA's flight control system was changed to the sensitive stick configuration, and the previous maneuvers repeated: phase 1 maneuvers, phase 2 HQDT maneuvers versus the un-timed task, and 4 phase 3 maneuvers versus the timed task. All of this was again repeated with the VISTA's flight control system in the added time delay configuration.

After completing the primary test points, enough fuel remained to fly 3 additional test points. These points were flown with the VISTA in the baseline configuration. 3 phase 3 maneuvers were flown versus the T-38 with a modified timed task: Instead of a 1 second roll-in for the first 3-g turn and a 2 second reversal for the second 3-g turn, the first 3-g turn was initiated as a maximum roll rate break turn and the unloaded reversal was also performed at maximum roll rate. The task was changed as an attempt to make the T-38 trajectory more closely resemble the flight test HUD Hi-fidelity target's trajectory.

Finally, 360° aileron rolls were flown with 0, 1 and 2 frames of time delay added to the flight test HUD update rate. This was done to evaluate the inherent time delay in the flight test HUD by comparing the angle between flight test HUD's horizon line and the actual horizon at maximum stabilized roll rates.

Phase 1: For all 3 flight control configurations, phase 1 maneuvers flown consisted of step inputs, stick raps, and vertical and horizontal captures of the T-38 target using the programmable HUD's fixed aiming reticle.

(continued)

6. RECOMMENDATIONS

R2. Redesign the hi-fidelity task to more closely resemble g-onset rates for an actual target

R1. When post flight video review will be used for data reduction, declutter the HUD as much as possible

COMPLETED BY	SIGNATURE	DATE
Capt Troy Asher	Troy A Asher	20 Mar 99

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Differences between the various flight control configurations were very evident.
- *Baseline case*: Responsive in pitch with a crisp initial response. The configuration was fairly predictable but stick sensitivity caused some over-control and minor overshooting of the target. Flying qualities in the lateral axis were similar. Roll rates were moderate to high, and sensitivity caused overshoots during lateral captures of the target. The sensitivities and overshoots were not as evident during pitch, heading and bank angle captures as they were when attempting to capture the airborne target vertically and horizontally.
- *Sensitive stick case*: Response was as expected. Longitudinally, initial response was abrupt and fast and the tendencies to over-control were amplified causing pitch "bobbles" and more overshoots. Laterally, not as much sensitivity was evident, but it did seem more sensitive than the baseline case.
- *Added time delay case*: Stick raps immediately showed the time delay which seemed like about ½ second. Initial response seemed sluggish which caused the pilot to increase stick input trying to get a response. This in turn, caused too large of an input once the aircraft responded to inputs, which caused large overshoots of intended banks, headings, and pitch angles. Longitudinally, predictability was poor and tracking the T-38 target was difficult without 3-4 overshoots. Laterally, time delay was not as large and predictability was better although still noticeably degraded.

Phase 2: Table D3 presents the results of the HQDT maneuvers as a summary of PIO ratings.
- *Baseline case*: High frequency, large amplitude stick movements resulted in converging oscillations. It was possible to reach full stick deflection inputs (stop-to-stop) at maximum rates without causing divergent PIOs.
- *Sensitive stick case*: Because of the high initial onset pitch rate, it was easy to unconsciously compensate or lead the target and I did a couple of times. After some practice, I was able to get a good set of data that showed a bounded PIO. The amplitude of the PIO did not seem to converge or diverge with increasing amplitude of inputs, but remained at a fixed amplitude.
- *Time delay case:* Initially capturing the target to get started with HQDT was difficult due to the apparent sluggishness caused by the time delay. As the amplitude of the stick input was increased, the pitch error diverged within 3-4 overshoots requiring discontinuing the task.

Phase 3: Table D4 presents the results of the operational tracking tasks (phase 3). The time and percentages the T-38 was held within the 5, 10 and 25 mil reticle circles is presented and was attained from post-flight video tape review. One problem noticed with data reduction was the HUD was left cluttered. While tracking, the TD box and flight path marker were left in the HUD. This did not hinder tracking the target at all, but made reviewing the video post flight difficult because the additional symbology covered the target occasionally. **When post flight video review will be used for data reduction, declutter the HUD as much as possible (R1).** Additionally, pilot ratings given in-flight directly after completing each task are presented. For all of the configurations, the defining parameter in task performance was lateral control. The target was very difficult to capture laterally. During the initial roll-in for the timed task, it was necessary to first match bank angles with the target and eliminate any lateral error, then pull the reticle to the target in the longitudinal axis (i.e. track one axis at a time). If the lateral error was not eliminated, unwanted lateral oscillations were encountered which detracted from task performance. This was the source of nearly all of the 2, 3 and 4 PIO ratings. Although generally a PIO or unwanted motions were not encountered in the pitch axis to a large extent, oscillations in the roll axis were ever present. Additionally, during the initial portion of the task, flying through the target's jet wash was a problem and was encountered on approximately 75% of the tasks. This caused additional lateral errors that amplified the problem discussed above. Also, the aircraft was very speed stable, so corrections to airspeed deviations during the tracking task caused pitch responses and degraded task performance.
- *Baseline case:* This was the easiest task to do. Lateral problems were the source of poor performance. Some learning effects were evident in the data (see table 2).
- *Sensitive stick case:* Initial capture of the target was easier than the baseline case due to the increased initial pitch rate response, but once the target was captured, fine tracking was more difficult due to over control. Corrections in the lateral axis took effect sooner and initially seemed easier, but the same over control problems eventually were evident as the tasks drew on. Again, a slight learning curve is evident in the data. Some regression of performance is noted which was either

caused by a poor initial lateral axis capture which affected the remainder of the task, or by pilot fatigue.
- *Time delay case*: Initial capture of the target was harder and overshoots of the target once reaching it made tracking difficult. This was most evident in the pitch axis, and although problems with the roll axis were still present, the poor pitch response was just as responsible for task performance in this case. More learning curve effects were evident in this case.

Additional Points: Upon completion of the planned profile, 3 additional points were added. After having flown against the hi-fidelity HUD target previously, it was evident that the designed hi-fidelity task was quite different than that flown by the T-38. The difference was the hi-fidelity target as designed, rolled and pulled to 3-g's in 1 second which was a faster g onset rate than the T-38. Additionally, the reversal was a reversal from 3-g's to the right to 3-g's to the left in 2 seconds, which was also a faster g onset rate than the T-38. To evaluate whether the two tasks could be made to look similar, the T-38 task was altered. The initial roll-in was changed to a maximum roll rate roll-in and pull to 3-g's at about 0.5 g/sec. and the rolling reversal was performed as an unloaded maximum roll rate maneuver followed by another pull to 3-gs at about 0.5 g/sec. The baseline configuration was then used to track the T-38 flying the modified task and this repeated 2 times. The modified task more closely resembled the hi-fidelity task. This indicated the design of the hi-fidelity task was not realistic, specifically g onset rates were too fast. **Redesign the hi-fidelity task to more closely resemble g-onset rates for an actual target (R2).** Results of this task are shown in table 2 as the last 3 test points listed.

Aileron Rolls: The results of the 360° ailerons are shown in table D5. The first aileron roll was flown in the baseline configuration. The second was flown baseline with an added 1 frame delay in HUD update rates. The third had 2 frames of added delay. All rolls were to the left and performed with full stick deflection except the first roll, which was near full deflection. After the 2 second delay case, a final roll was flown in the baseline configuration with no time delay for comparison. This was flown to the right. Noticeable differences were evident between the flight test HUD horizon and the actual horizon after roll rate was constant. The angles in table 2 were estimated by reviewing HUD video. Also, the flight test HUD tended to split into two horizon lines at a 5-10° angle to each other at maximum roll rates.

Table D3
SUMMARY OF PILOT RATINGS FROM
HANDLING QUALITIES DURING TRACKING (HQDT)

Test Point	Record No.	PIOR	Fuel (lbs)
Baseline	2	1	6,300
Sensitive St.	8	4	5,400
Time Delay	15	5	4,700

Note: PIOR – pilot-induced oscillation rating

Table D4
SUMMARY OF PILOT RATINGS FROM OPERATIONAL TRACKING

Test Point	Record No.	Time in 5 mil circle/ Total time	Pct in 5 mil	Time in 10 mil circle/ Total time	Pct in 10 mil	Time in 25 mil circle/ Total time	Pct in 25 mil	CHR	PIOR	Fuel (lb)
Baseline	3	16/40	40	26/40	65	37/40	92	5	2	6,200
Baseline	4	13/37	35	21/37	57	31/37	84	5	2	6,000
Baseline	5	23/40	57	29/40	72	35/40	88	4	2	5,900
Baseline	6	14/40	35	24/40	60	32/40	80	5	2	5,800
Sensitive St.	9	7/38	18	17/38	45	32/38	84	6	4	5,200
Sensitive St.	11	14/38	37	25/38	66	31/38	82	6	4	5,200
Sensitive St.	12	19/40	48	25/40	63	35/40	88	5	3	5,000
Sensitive St.	13	12/38	32	20/38	53	29/38	76	5	4	4,800
Time Delay	16	5/40	13	13/40	33	33/40	83	7	3	4,500
Time Delay	17	7/37	19	13/37	35	29/37	78	7	4	4,400
Time Delay	18	10/36	28	19/38	50	31/38	82	6	3	4,200
Time Delay	19	8/36	22	24/40	60	34/40	85	5	3	4,100
Baseline	20	17/35	49	24/35	67	31/35	89	4	2	4,000
Baseline	21	16/38	42	25/38	66	34/38	89	4	2	3,800
Baseline	22	14/34	41	20/34	59	29/34	83	5	2	3,700

Notes: 1. mil - milliradian
2. CHR - Cooper-Harper rating
3. PIOR - pilot-induced oscillation rating

Table D5
HEAD-UP DISPLAY (HUD) TIME DELAY CHARACTERIZED AS DIFFERENCE BETWEEN HUD HORIZON AND ACTUAL HORIZON AFTER FULL DEFLECTION 360-DEGREE ROLLS

Time delay (frames)	Degrees between head-up display (HUD) horizon and horizon after 360-degree roll	Remarks
0	15	Split Horizon (5 to 10 degrees)
1	25	Split Horizon (5 to 10 degrees)
2	30	Split Horizon (5 to 10 degrees)
0	15	Split Horizon (5 to 10 degrees)

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE VISTA NF-16	2. SERIAL NUMBER 86-0048	

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO HAVE TRACK / VISTA #451	B. FLIGHT NO / DATA POINT Flight #8 – Lo-Fidelity Target	C. DATE 23 Mar 99
D. FRONT COCKPIT *(Left Seat)* Williams	E. FUEL LOAD 7,600	F. JON M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)* Peer	H. START UP GR WT / CG	I. WEATHER Clr, 10+ Vis
J. TO TIME / SORTIE TIME 0910L / 1.3	K. CONFIGURATION / LOADING Ctrline Tank	L. SURFACE CONDITIONS 250/15
M. TARGET ACFT / SERIAL NO N/A	N. TARGET CREW N/A	O. TARGET TO TIME / SORTIE TIME N/A

4. PURPOSE OF FLIGHT / TEST POINTS

4.1. Evaluate the HAVE TRACK Baseline configuration against a Low-Fidelity HUD Tracking task during HQDT.
4.2. Evaluate the HAVE TRACK Baseline configuration against a Low-Fidelity HUD Tracking task during repeated phase 3 tasks.
4.3. Evaluate the HAVE TRACK high stick sensitivity configuration against a Low-Fidelity HUD Tracking task during HQDT.
4.4. Evaluate the HAVE TRACK high stick sensitivity configuration against a Low-Fidelity HUD Tracking task during repeated phase 3 tasks.
4.5. Evaluate the HAVE TRACK time delay configuration against a Low-Fidelity HUD Tracking task during HQDT.
4.6. Evaluate the HAVE TRACK time delay configuration against a Low-Fidelity HUD Tracking task during repeated phase 3 tasks
4.7 Conduct low amplitude, high amplitude, and proportional amplitude HQDT on the HAVE TRACK Baseline configuration.
4.8 Conduct low amplitude, high amplitude, and proportional amplitude HQDT on the HAVE TRACK high stick sensitivity configuration.
4.9 Conduct low amplitude, high amplitude, and proportional amplitude HQDT on the HAVE TRACK time delay configuration.
4.10.Conduct 1g PTI step inputs at the test condition (0.75 Mach, 15K PA) for each configuration.
4.11.Conduct 3g manual frequency sweeps at the test condition (0.75 Mach, 15K PA) for each configuration.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

5.1 OVERALL: All objectives were met. Safety trips occurred on objectives 4.3, 4.8, and 4.9, but enough enough qualitive and quantitative data was gathered. For details of the flight test program, reference the HAVE TRACK test plan. For details of the HUD and configuration parameters, reference the AFSC Form 5314, VISTA Flt#443.

5.2 TEST CONDITIONS: Altimeter was set to 29.92 for all test points. All handling qualities tasks were accomplished with feet on the floor. For HQDT evaluations, a firm grip on the stick was used with the right arm not braced against the aircraft or the pilot's leg. Stick movements for constant amplitude HQDT were limited to set stick movement inputs for and aft. The level of these inputs was adjusted to maintain a symmetric error signal. Otherwise, the inputs were step inputs with fast stick movement once zero error was crossed. For proportional HQDT, the amplitude of the step inputs was based on the relative rate of of the error. Once the step input was applied no attempt was made to adjust its level. Initial error prior to starting HQDT was less than 5 mils in the pitch axis alone. Roll HQDT was not attempted. For phase 3 evaluations, there were no restrictions on techniques to produce the best performance. After each configuration change and before HQDT, a phase one evaluation of the aircraft's time delay, predictability, undesired motions, sensitivity, and control harmony for the pitch and roll axes were evaluated to verify the configuration and to buildup prior to HQDT evaluations.

Continued

6. RECOMMENDATIONS (in order of priority)

1. **Revise the performance criteria for the Lo-fidelity task to 10 mil – adequate, 5 mil - desired, and place criteria to the bank angle as well.**

COMPLETED BY	SIGNATURE	DATE
TIM WILLIAMS, CAPT, USAF		18 Mar 99

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5.3 TEST RESULTS: The following table summarizes the test results of the flight. A CHR and PIOR was assigned immediately after each maneuver. Video review indicates post flight analysis of performance, which in some cases affected the CHR.

Rec#	Fuel	CONFIG	PH 2 or 3	PIOR	CHR	VIDEO PERF	COMMENTS
4	6.8	Baseline	Lo-fi 2	<4	x	x	Definite level one aircraft, contrlable, predit
5	6.5	Baseline	Lo-fi 3	2	3	Desired	Very predictable, criteria too large, roll
6	6.3	Baseline	Lo-fi 3	2	2	Desired	control an afterthought
7	6.2	Baseline	Lo-fi 3	2	2	Desired	
9	6.0	Stick sens	Lo-fi 2	5	x	x	Safety trip
10	5.8	Stick sens	Lo-fi 3	5	4	Desired	Many overshoots on gross acq, lots of undesi
11	5.6	Stick sens	Lo-fi 3	5	4	Desired	motion while fine tracking
12	5.4	Stick sens	Lo-fi 3	5	3	Desired	
14	5.1	Time delay	Lo-fi 2	4	x	x	Bounded oscillations
15	5.0	Time delay	Lo-fi 3	4	5	Adeq+	Gross acq difficult, hard to predict
16	4.8	Time delay	Lo-fi 3	4	4	Desired	
17	4.6	Time delay	Lo-fi 3	4	4	Desired	
18	4.5	Baseline	Hi-fi 2	<4	x	x	Const amp, small input
		Baseline	Hi-fi 2	<4	x	x	Const amp, large input
		Baseline	Hi-fi 2	<4	x	x	Proportional amp
19	4.0	Stick sens	Hi-fi 2	5	x		Const amp, small input
		Stick sens	Hi-fi 2	5	x		Const amp, large input, Safety trip
20	3.7	Stick sens	Hi-fi 2	5	x		Proportional amp
21	3.4	Time delay	Hi-fi 2	4	x		Const amp, small input
		Time delay	Hi-fi 2	4	x		Const amp, large input
		Time delay	Hi-fi 2	4	x		Proportional amp
22	3.0	Baseline	Hi-fi 3	3	5	Adeq++	Almost desired, lateral offset problems
23	2.9	Stick sens	Hi-fi 3	5	6	Adeq	pitch bobble, quick gross acq
24	2.8	Time delay	Hi-fi 3	4	7	Adeq	Unpredict in roll

5.3.1 BASELINE CONFIGURATION – LO-FIDELITY COMMENTS: Phase 1 evaluation verified the baseline configuration seen on previous missions. HQDT for the lo-fidelity task showed some undesirable motion but gross acquisitions were dampened in less than 2 small overshoots. Fine tracking showed predictable, quickly dampened response. For phase 3 tasks, the performance criteria was too large. It was fairly easy to maintain desired performance, and gross acquisitions were captured within 5 mils. There was no penalty for not adjusting the bank to the commanded bank angle. **Revise the performance criteria for the Lo-fidelity task to 10 mil – adequate, 5 mil - desired, and place criteria to the bank angle as well.** Performance improved throughout the repeated tasks. Workload remained the same throughout the tasks. The safety pilot noted the evaluation pilot likes to fly tasks within a certain frequency band.

5.3.2 SENSITIVE STICK CONFIGURATION – LO-FIDELITY COMMENTS: Phase 1 evaluation verified the sensitive stick configuration seen on previous missions. Proportional HQDT for the lo-fidelity task showed divergent oscillations in the pitch axis. A safety trip occurred approximately 15 seconds into the task. For the phase 3 events, gross acquisitions caused 4 or more overshoots, requiring the pilot to freeze the stick to arrest a PIO. Fine control was fairly predictable for a slowly varying target, but using open loop control inputs – applying a stick input and waiting for a response before applying another input- caused small oscillations. Desired performance was attained due to the large performance criteria, but the pilot still had to compensate to avoid a PIO.

5.3.3 TIME DELAY CONFIGURATION COMMENTS: Phase 1 evaluation verified the time delay configuration seen on previous missions. HQDT for the lo-fidelity task showed a wild but bounded output. For phase 3 tasks, the response for gross acquisitions was very unpredictable with approximately 3 overshoots. It was difficult to shape the inputs to dampen the response. More than likely, the pilot's inputs coupled into the response to cause oscillations. On the first task, less than desired performance was obtained primarily due to the pitch unpredictability. General improvement in task performance occurred on the next two tasks as the proper control compensation for the time delay configuration was determined.

5.4.1 HQDT – BASELINE CONFIGURATION – HI-FIDELITY TARGET – HQDT for the baseline configuration was conducted with small stick inputs, large inputs, and proportional gain inputs using the hi- fidelity HUD task. Some leading inputs especially with aft stick occurred. Also, asymmetric error output was present with the larger error occurring below the target, toward the pitch trim point. Baseline configuration showed very little tendency to diverge in the proportional input HQDT

5.4.2 HQDT – SENSITIVE STICK CONFIGURATION – HI-FIDELITY TARGET – HQDT for the sensitive stick configuration was conducted with small stick inputs, large inputs, and proportional gain inputs using the hi- fidelity HUD task. Some leading inputs especially with aft stick occurred. Also, asymmetric error output was present with the larger error occurring below the target, toward the pitch trim point. Sensitive stick configuration showed great propensity to diverge during HQDT. Safety trips occurred during the large inputs and proportional input HQDT. At least 15 seconds of data was recorded prior to the safety trips.

5.4.3 HQDT – TIME DELAY CONFIGURATION – HI-FIDELITY TARGET – HQDT for the time delay configuration was conducted with small stick inputs, large inputs, and proportional gain inputs using the hi- fidelity HUD task. Some leading inputs especially with aft stick occurred. Also, asymmetric error output was present with the larger error occurring below the target, toward the pitch trim point. With the time delay, it was difficult to predict the aft force required to attain symmetric output. Time delay configuration showed large oscillations that tended to continue into a bounded oscillation at a lower frequency than the stick-sensitive or baseline configuration.

5.5.1 PHASE 3 – BASELINE CONFIGURATION – HI-FIDELITY TARGET – A phase 3 evaluation was conducted on the hi fidelity target to determine any learning curve on this final VISTA flight. Overall, it took approximately 6 seconds to achieve adequate performance and 8 seconds for desired performance. After the reversal, desired performance was achieved in approximately 7 seconds, but there were minor lateral deviations outside the desired criteria. Overall, performance was adequate but close to desired. Principle difficulty was the ability to quickly determine the bank angle solution to minimize the lateral error.

5.5.2 PHASE 3 – SENSITIVE STICK CONFIGURATION – HI-FIDELITY TARGET – A phase 3 evaluation was conducted on the hi fidelity target to determine any learning curve on this final VISTA flight. Overall, gross acquisition to the adequate criteria took approximately 4 seconds and after the reversal, about 5 seconds was required for adequate performance. Desired performance was not possible due to small oscillations in the pitch and roll axes. The quick acquisition was offset by the PIO sensitivity problems.

5.5.2 PHASE 3 – TIME DELAY CONFIGURATION – HI-FIDELITY TARGET – A phase 3 evaluation was conducted on the hi fidelity target to determine any learning curve on this final VISTA flight. Overall, gross acquisition to the adequate criteria took approximately 8 seconds and after the reversal, about 8 seconds was required for adequate performance. The pitch response was fairly predictable, and open loop control worked fairly well in adjusting the pitch stick forces. Unfortunately, lateral control was very unpredictable, and performance fell outside the adequate criteria at times.

5.6 PTI, FREQUENCY SWEEPS – PTIs and manual frequency sweeps were conducted on the baseline, sensitive stick, and time delay configurations. For the 3 g manual frequency sweeps, the bank was varied to maintain altitude with the varying g loading.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
VISTA NF-16	86-0048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO HAVE TRACK / VISTA #452	B. FLIGHT NO / DATA POINT Flight #9 – Low Fidelity HUD	C. DATE 23 Mar 99
D. FRONT COCKPIT *(Left Seat)* Cassidy	E. FUEL LOAD 7,600	F. JON M96J0200
G. REAR COCKPIT *(Right Seat and rest of crew)* Hutchinson	H. START UP GR WT / CG	I. WEATHER Clear,10
J. TO TIME / SORTIE TIME 1154L / 1.3	K. CONFIGURATION / LOADING Ctrline Tank	L. SURFACE CONDITIONS Temp 1C, 240/17G20, Alt 30.09
M. TARGET ACFT / SERIAL NO N/A	N. TARGET CREW N/A	O. TARGET TO TIME / SORTIE TIME N/A

4. PURPOSE OF FLIGHT / TEST POINTS

1. Perform Phase 1,2,3 maneuvering against the low fidelity HUD target with all three flight control configurations. Perform one each of a Phase 1 warm up and Phase 2 HQDT. Perform three Phase 3 operational handling tracking tasks.
2. Perform Phase 2 HQDT against the high fidelity target using constant small amplitude control inputs, constant large amplitude control inputs and inputs proportional to the error.
3. Perform a set of Phase 3 tracking against the high fidelity HUD target using all 3 flight control configurations.
4. Perform PTI step inputs and manual frequency sweeps for each flight control configuration. Accomplish the manual frequency sweeps in a 3G turn with G varying from 2-4.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

All maneuvers were completed. All maneuvers were accomplished at 15,000 ft and .75 M. Maneuvers were accomplished with no rudder inputs. Manual frequency sweeps were accomplished trimmed for 3.0 Gs.

The baseline configuration was first evaluated while doing constant amplitude HQDT against the low fidelity target. A slight amount of unwanted motion was noted during HQDT. Desired performance was easy to achieve on the tracking tasks. The task was too easy. Workload was minimal and the task became slightly easier.

The sensitive stick configuration was evaluated while doing constant amplitude HQDT against the low fidelity target. This configuration was tough to fly. HQDT felt like a bucking bronco. The oscillations were bounded Desired performance was achieved during the tracking tasks with unwanted motions noted. Workload was high. I had to fight the oscillations and it felt like I was trying to balance on the head of a pin. The task was too easy to break out this degraded flight control configuration in terms of task performance. I noticed no learning curve on this task.

The time delay configuration was evaluated while doing constant amplitude HQDT against the low fidelity target. HQDT was a slow, bounded oscillation. I felt like I was 180 degrees out of phase with the jet. Tracking was initially adequate. I learned to compensate enough to get desired performance on the last 2 tracking tasks. Workload was high with a lot of pitch bobbles noted during target maneuvers. Desired and adequate criteria were too generous to break out this degraded flight control configuration.

Different techniques for HQDT were tried against the high fidelity target and all three flight control configurations. Constant amplitude HQDT, either small or large amplitude, would break out a PIO 3 ,4 or 5. The baseline and sensitive stick configurations resulted in a bounded oscillation. It felt like the jet was just following what I was asking it to do. The time delay configuration was a bounded oscillation but it felt like a bucking bronco. The proportional amplitude HQDT gave me a better feeling for the PIO susceptibility of the jet. I felt it was a better way to wring out the jet. The baseline and sensitive stick configurations were both excellent at 3 Gs while the time delay resulted in an unbounded oscillation.

Continued

6. RECOMMENDATIONS (in order of priority)

To determine a valid PIO rating for a new flight control system, proportional HQDT should be used.
Low fidelity tracking performance should use the same adequate and desired performance criteria as the high fidelity and the T-38 tracking tasks.

COMPLETED BY	SIGNATURE	DATE
EDWARD V. CASSIDY, Captain, USAF	Edward V. Cassidy	2 Apr 99

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5. RESULTS OF TESTS *(Continued from front)*

All three configurations were tested against the high fidelity HUD tasks. Since I switched flight control configurations for each task, I felt that the I spent the first part of each task feeling the control system which hampered tasks performance. Performance was adequate for the baseline and sensitive stick and was not adequate for the time delay configuration. Significant lateral oscillations were noted for the sensitive stick.

Manual frequency sweeps and step PTIs were performed. The aircraft was trimmed for 3 Gs for the frequency sweeps. G varied from 2-4 Gs. The sensitive stick frequency sweep was sloppy with G varying from 1-5 Gs.

The following summarizes HQRs and PIORs for each run:

Config	Target	HQDT PIOR	Ph 3 PIOR	Ph 3 HQR
Baseline	Lo Fi	3		
Baseline	Lo Fi		1	3
Baseline	Lo Fi		1	3
Baseline	Lo Fi		1	3
Sensitive	Lo Fi	4		
Sensitive	Lo Fi		3	4
Sensitive	Lo F		3	4
Sensitive	Lo Fi		3	4
Time Delay	Lo Fi	4		
Time Delay	Lo Fi		3	6
Time Delay	Lo Fi		3	4
Time Delay	Lo Fi		3	4
Baseline	Hi Fi-small amp	3		
Baseline	Hi Fi-large amp	3		
Baseline	Hi Fi-Proportional	1		
Sensitive	Hi Fi-small amp	3		
Sensitive	Hi Fi-large amp	3		
Sensitive	Hi Fi-Proportional	1		
Time Delay	Hi Fi-small amp	4		
Time Delay	Hi Fi-large amp	4		
Time Delay	Hi Fi-Proportional	5		
Baseline	Hi Fi		1	5
Sensitive	Hi Fi		3	6
Time Delay	Hi Fi		3	7

DAILY INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
NF-16D	86048

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO	B. FLIGHT NO / DATA POINTS	C. DATE
Have Track / VISTA #453	Flight #10 - Lo-Fidelity HUD Target	26 March 1999
D. FRONT COCKPIT (Left Seat)	**E. FUEL LOAD**	**F. JON**
Capt Troy Asher	7700 lb.	M96J0200
G. REAR COCKPIT (Right Seat)	**H. START UP GR WT / CG**	**I. WEATHER**
Mr. Jeff Peer	29,500 / 36.9%	30 BKN 40 OVC Vis 10
J. TO TIME / SORTIE TIME	**K CONFIGURATION / LOADING**	**L. SURFACE CONDITIONS**
1413 / 1.3	Centerline tank	0°C, Wind 3107, Altim 30.22, Dry
M. CHASE ACFT / SERIAL NO	**N. CHASE CREW**	**O. CHASE TO TIME / SORTIE TIME**
n/a	n/a	n/a

4. PURPOSE OF FLIGHT

To evaluate the VISTA's handling qualities when configured with the three HAVE TRACK flight control configurations by tracking a *HUD generated target that is flying a Mil-Std-1797A profile ("low-fidelity").* Evaluate handling qualities via pilot comments and ratings.

The following maneuvers were flown in each flight control configuration (baseline, sensitive stick, and added time delay) using the virtual HUD target:

–Open loop and semi-closed loop maneuvers (stick raps, step inputs, pitch, bank and heading captures)
–Tracking of the low-fidelity HUD target using the Handling Qualities During Tracking (HQDT)
–Tracking of the low-fidelity HUD target in an "operationally representative" manner (maintaining the smallest error possible) repeated 3 times
–Tracking using the Handling Qualities During Tracking (HQDT) technique with the target flying the high fidelity profile (a re-fly test points from HAVE TRACK flight #6)
–Tracking of the HUD target in an "operationally representative" manner (maintaining the smallest error possible) with the target flying the high fidelity profile (to evaluate learning curve effects)
–PTI step inputs at the test condition (0.75 Mach, 15K PA, 1-g) for each configuration (re-fly for data)
–Manual frequency sweeps at the test condition (0.75 Mach, 15K PA, 3-g) for each configuration (re-fly for data)
–Phase 1 and 2 tracking of an altitude stabilized, HUD target in straight and level, unaccelerated flight

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Overall: All objectives were met. All maneuvers were accomplished as planned. The low-fidelity (Mil-Std) HUD target was found to have merit, but some modifications would have to be made to allow evaluation of the lateral axis or learning curve effects. HQDT techniques were varied slightly and some differences noted, but pilot ratings were similar to those obtained previously.

Phase 1 Maneuvers: See the Daily Initial Flight Test Reports from flights 6 and 7 for comments regarding phase 1 maneuvers flown in the three different flight control configurations. No changes were noted on this sortie.

Phase 2 Maneuvers: See table D6 for the results of HQDT flown in the three different configurations versus the low-fidelity HUD target. Compared to the high-fidelity target, the low-fidelity target allowed maneuvers about a 1-g target at small amplitudes interspersed with large amplitude capture tasks as the target jumped through its profile. It also allowed simple separation of the longitudinal and lateral axes as the target profile was primarily a pitch capturing exercise with limited bank captures. For HQDT, small step inputs were used to correct to the new target position, and at the zero tracking error point, the input was reversed in an equal amount the opposite direction. These constant amplitude, reversing step inputs were repeated continuously. If PIO was not encountered, the step inputs were increased in amplitude, in incremental amounts, until task completion (75 seconds) or a divergent PIO occurred. The low-fidelity task could be used alone (*without* HQDT superimposed on top of it) to investigate PIO susceptibility. The target profile contained abrupt, step changes in flight path, much like HQDT, that could be increased or decreased in size (amplitude) depending on the gain selected by the VISTA safety pilot. Tracking this HUD target for PIO purposes would be different than the phase 3 task, in that instead of desired and adequate performance criteria, zero tracking error would be the only requirement.

- *Baseline configuration*: Some minor pitch sensitivities were noted, but oscillations about zero error were generally convergent. As amplitude was increased, overshoots were initially larger, but decreased in size as the maneuver continued, to some smaller, constant amplitude. In this configuration, the aircraft followed command inputs well.

6. RECOMMENDATIONS

R1. For the low-fidelity HUD task, reduce the performance criteria circles to 5 mils and 10 mils for desired and adequate performance, respectively
R2. Do not use the low-fidelity HUD target as the primary target for handling qualities evaluations. A more realistic target, such as the high-fidelity HUD target, is needed for an accurate and complete evaluation
R3. Add a non-maneuvering, altitude stabilized target to the programmable HUD as a standard feature for use in phase 1 and phase 2 maneuvers

COMPLETED BY	SIGNATURE	DATE
Capt Troy Asher	T A Asher	20 Mar 99

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-Sensitive stick configuration: The sensitivity in the stick caused over-control and larger pitch overshoots than commanded by the size of the control input. Although the overshoots were larger than commanded, as inputs were reversed, the aircraft followed commands immediately and overshoots in the opposite direction were equal in size. As the amplitude of the control inputs was increased, the oscillations grew larger, but remained bounded about zero error and did not diverge.
-Added time delay configuration: Stick inputs were limited to small, abrupt step inputs. When the aircraft did not respond immediately, the input was patiently held constant until response was noted. At zero error, the input was abruptly reversed (step input) to one of equal size in the opposite direction. Again, the aircraft would not initially respond and rather than *increasing* the input to force a response, it was patiently held constant until the aircraft responded and the tracking error was driven to zero. As this was continued, PIO was apparent, but the oscillations were bounded. Due to the large response times involved, larger amplitudes were never reached during this task. If control inputs would have been proportional to the error observed (i.e. as overshoots got larger, inputs were increased to aggressively correct for them) rather than patiently waiting with constant small inputs, a divergent oscillation would have been encountered, just as when this maneuver was flown versus the hi-fidelity target.

Phase 3 Maneuvers: See table D7 for a summary of pilot ratings for these maneuvers. The primary difference between low-fidelity HUD tracking task and the high-fidelity task was in lateral control. In the high-fidelity task, if lateral error was not controlled, task performance was significantly degraded. In the low-fidelity task, bank changes were commanded, but did not affect the pitch error at all. This allowed precise pitch pointing and greatly improved task performance. In all configurations, adequate performance was easily attainable, and desired performance was generally attainable. The reason for ratings of 4 instead of 3 was due mostly to the moderate amount of workload required. The smaller 5 and 10 mil error circles designed for the high-fidelity task would have been a more appropriate measure of task performance and would have driven pilot gain higher. **For the low-fidelity HUD task, reduce the performance criteria circles to 5 mils and 10 mils for desired and adequate performance, respectively (R1).** Evaluation of a single axis at a time was much easier. Despite this, the high-fidelity HUD tracking task would provide a better overall evaluation of aircraft handling qualities. The effects on performance of interactions between axes during tracking are vital in knowing how the aircraft will perform. **Do not use the low-fidelity HUD target as the primary target for handling qualities evaluations. A more realistic target, such as the high-fidelity HUD target, is needed for an accurate and complete evaluation (R2).**
-Baseline configuration: The aircraft was predictable, had crisp initial response and harmony was good. Desired performance was easily obtained, and ratings of 4 were only given due to moderate pilot workload. Ratings would have been the same if the 5 mil circle was used as desired performance criteria instead of the 10 mil circle.
-Sensitive stick configuration: Initial overshoots due to over control were responsible for the first rating of 5 (adequate performance), but after one try, compensation techniques were learned and desired performance was again easily obtained. Ratings would have been similar with the 5 mil circle used to define desired performance. Compensation consisted of lowered pilot gain and a lighter grip on the stick.
-Added time delay configuration: Many overshoots were noticed in this configuration. The initial rating of 6 was due to the considerable amount of pilot workload, but the learning curve was steep. After one try, desired performance was again easy to obtain. Compensation consisted of patiently waiting for inputs to take effect and leading the target (taking inputs out before reaching the target). Again, the smaller error circles would have been a more accurate predictor of aircraft handling qualities.

HQDT on Hi-Fi target: These test points were a repeat from flight 6, due to concerns that the three pilots in the group were using different HQDT techniques and that enough data was not obtained the first time for precise analysis. Pilot ratings are summarized in table D8. The "standardized" technique used was that described in the Phase 2 paragraph above. In each configuration, a build-up approach was employed. First, small amplitude, reversing step inputs were used for 15 seconds. Then, large amplitude, reversing step inputs were used for 15 seconds. Finally, the amplitude of the input was "swept" or increased proportionately to the size of the error observed for 15 seconds. Large overshoots were countered with large amplitude reversals and small overshoots got small amplitude corrections. The safety pilot monitored timing and called every 15 seconds. The entire buildup for each configuration was logged under the same record number with short periods of inactivity between steps, except the sensitive stick configuration. During the sensitive stick configuration, large input HQDT, a pitch rate safety trip was encountered, and the maneuver discontinued

(record 17). The next record (18) was the proportional HQDT method with the sensitive stick configuration. Notable differences between methods were *not* observed *except* in the time delay case where, as the amplitude of the input was increased, the overshoots got larger and eventually the oscillation diverged. The best technique for HQDT would be as follows:

> Start HQDT with small amplitude inputs and reverse them at zero error in a gentle manner (ramps). If this results in no PIO, then increase the amplitude slowly until large amplitudes are being used while the reversals are still gentle. If still no PIO is encountered, then start over with small amplitude inputs, but make the reversals abrupt, like step inputs. If no PIO is encountered, again slowly increase amplitude until reaching a point where large amplitude inputs are being used with as abrupt as possible reversals. This is the desired end point. If PIO is encountered anywhere along the way, terminate the buildup and make appropriate pilot comments and ratings.

Phase 3 on Hi-Fi target: These test points were also a repeat of earlier test points. The purpose of repeating them was to evaluate learning curve effects as they may have occurred throughout all three of the missions. The results are presented in table D9. Compared to the pilot ratings from flights 6 and 7, no appreciable changes can be seen. The task was different enough from the low-fidelity task that learning effects did not transfer to the high-fidelity task. If I had performed each high-fidelity task twice, some learning effects may have been noticed between events, but learning did not seem to transfer between sorties. Trouble controlling the lateral axis was still main reason for less than desired performance.

PTI Step Inputs and Frequency Sweeps: These maneuvers were flown as planned. Frequency sweeps were flown from a level 3-g turn. The aircraft was trimmed to maintain 3-g before beginning the maneuver. It took about 15 seconds of steady nose-up trim to reach the trimmed condition. During the sensitive stick configuration, a safety trip was encountered at around the 0.5 to 1 Hz area of the frequency sweep. The maneuver was not repeated.

Additional Test Point: After the T-38 Target sortie, I noticed not having an airborne target to reference during phase 1 maneuvers was a detriment. Therefore, a non-maneuvering, altitude stabilized HUD target was added and phase 1 and 2 maneuvers performed on it in the baseline and added time delay configurations. The target was generated by setting the roll (TTK Roll) and azimuth (TTK Az) settings for the high-fidelity HUD target to zero. This provided a stable target in the HUD that mimicked a straight-and-level aircraft. The target was realistic and made semi-closed loop phase 1 maneuvers much more insightful. Pitch and roll sensitivities were much easier to see, and predictability was easier to judge. Also, HQDT could be performed easily on the target. Add a non-maneuvering, altitude stabilized target to the programmable HUD as a standard feature for use in phase 1 and phase 2 maneuvers (R3).

Table D6
SUMMARY OF PILOT RATINGS FROM HANDLING QUALITIES DURING TRACKING (HQDT) VERSUS LOW-FIDELITY HEAD-UP DISPLAY (HUD) TARGET

Test Point	Record No.	PIOR	Fuel (lbs)
Baseline	2	1	6,800
Sensitive St.	7	4	5,900
Time Delay	12	4	5,100

Note: PIOR – pilot-induced oscillation rating

Table D7
SUMMARY OF PILOT RATINGS FROM OPERATIONAL TRACKING VERSUS LOW-FIDELITY HEAD-UP DISPLAY (HUD) TARGET

Test Point	Record No.	CHR	PIOR	Fuel (lbs)
Baseline	3	4	2	6,700
Baseline	4	4	2	6,400
Baseline	5	3	2	6,300
Sensitive St.	8	5	3	5,700
Sensitive St.	9	4	3	5,500
Sensitive St.	10	3	3	5,300
Time Delay	13	6	4	5,000
Time Delay	14	4	3	4,800
Time Delay	15	4	4	4,600

Notes: 1. CHR – Cooper-Harper rating
2. PIOR – pilot-induced oscillation rating

Table D8
SUMMARY OF PILOT RATINGS FROM HANDLING QUALITIES DURING TRACKING (HQDT) VERSUS HIGH-FIDELITY HEAD-UP DISPLAY (HUD) TARGET

Test Point	Record No.	PIOR	Fuel (lbs)
Baseline - Small Amplitude	16	1	4,500
Baseline - Large Amplitude	16	1	4,500
Baseline - Proportional	16	1	4,500
Sensitive - Small Ampl	17	4	4,200
Sensitive - Large Ampl	17	5	4,200
Sensitive - Proportional	18	4	3,800
Time Delay - Small Ampl	19	3	3,700
Time Delay - Large Ampl	19	5	3,700
Time Delay - Proportional	19	5	3,700

Note: PIOR – pilot-induced oscillation rating

Table D9
SUMMARY OF PILOT RATINGS FROM OPERATIONAL TRACKING VERSUS HIGH-FIDELITY HEAD-UP DISPLAY (HUD) TARGET

Test Point	Record No.	CHR	PIOR	Fuel (lbs)
Baseline	20	5	3	3,400
Sensitive St.	21	6	4	3,200
Time Delay	22	7	4	3,000

Notes: 1. CHR – Cooper-Harper rating
2. PIOR – pilot-induced oscillation rating

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APPENDIX E

FLIGHT TEST RESULTS

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FLIGHT TEST RESULTS

Table E1
FREQUENCY SWEEP FOR BASELINE FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Record No.	R. Smith VFR CHR	R. Smith VFR PIOR
A	448	20 Mar 99	23	No Data (ND)	ND
A	453	26 Mar 99	24	7	4
B	445	18 Mar 99	25	6	3
B	452	23 Mar 99	31	ND	ND
C	444	18 Mar 99	22	6	3
C	451	23 Mar 99	26	6	3

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number
3. Date - Date mission was flown
4. Record - Record number, used for data reduction
5. R. Smith VFR CHR - Cooper-Harper Rating (CHR) using R. Smith criteria, not using head-up display (HUD) error signal
6. R. Smith VFR PIO - Pilot-induced Oscillation Rating (PIOR) using R. Smith criteria, not using HUD error signal

Table E2

PHASE 2 HANDLING QUALITIES DURING TRACKING (HQDT) FOR BASELINE FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record	HQDT Type	Pilot PIOR	R. Smith PIOR	R. Smith VFR PIOR
A	449	20 Mar 99	T-38	2	Small/Large Amp.	1	N/A	ND
B	447	19 Mar 99	T-38	2	Prop. Amp.	1	N/A	4
B	447	19 Mar 99	T-38	15	Prop. Amp.	2	N/A	3
B	447	19 Mar 99	T-38	21	Prop. Amp.	2	N/A	3
C	446	19 Mar 99	T-38	1	Small/Large Amp.	3	N/A	3
A	448	20 Mar 99	Hi-fi	2	Small/Large Amp.	1	4	4
A	448	20 Mar 99	Hi-fi	28	Small/Large Amp.	1	No Data (ND)	ND
A	453	26 Mar 99	Hi-fi	16	Small Amp.	1	3	3
A	453	26 Mar 99	Hi-fi	16	Large Amp.	1	4	3
A	453	26 Mar 99	Hi-fi	16	Prop. Amp.	1	4	4
B	445	18 Mar 99	Hi-fi	2	Prop. Amp.	2	4	4
B	452	23 Mar 99	Hi-fi	17	Small Amp.	3	ND	ND
B	452	23 Mar 99	Hi-fi	18	Large Amp.	3	ND	ND
B	452	23 Mar 99	Hi-fi	19	Prop. Amp.	1	ND	ND
C	444	18 Mar 99	Hi-fi	2	Small/Large Amp.	3	3	4
C	451	23 Mar 99	Hi-fi	18	Small Amp.	3	3	3
C	451	23 Mar 99	Hi-fi	18	Large Amp.	3	4	4
C	451	23 Mar 99	Hi-fi	18	Prop. Amp.	3	2	4
A	453	26 Mar 99	Lo-fi	2	Small/Large Amp.	1	3	3
B	452	23 Mar 99	Lo-fi	3	Prop. Amp.	3	3	3
C	451	23 Mar 99	Lo-fi	4	Small/Large Amp.	3	3	3

Notes:
1. Pilot - Pilot who flew mission
2. Mission No. - Calspan designated mission number (used for data reduction)
3. Date - Date mission was flown
4. Target - Target type [T-38A, high-fidelity (hi-fi) head-up display (HUD) task, or low-fidelity (lo-fi) HUD task]
5. Record No. - Record number, used for data reduction
6. HQDT Type - Handling qualities during tracking (HQDT)(small const. amp., large const. amp., proportional amp.)
7. Pilot PIOR - Pilot designated pilot-induced oscillation rating (PIOR) (airborne)
8. R. Smith PIOR - PIOR derived using R. Smith criteria
9. R. Smith VFR PIOR - PIOR derived using R. Smith criteria, not using HUD error signal

Table E3
PHASE 3 OPERATIONAL TRACKING FOR BASELINE FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record No.	5 Mil (pct)	10 Mil (pct)	25 Mil (pct)	Pilot CHR	PEP	APP	Adj. Rating	Agree?	Pilot PIOR	R. Smith CHR	R. Smith PIOR	R. Smith VFR CHR	R. Smith VFR PIOR
A	449	20-Mar-99	T-38	3	40.00	65.00	92.00	5	A	A	5	Y	1	N/A	N/A	6	3
A	449	20-Mar-99	T-38	4	35.00	57.00	84.00	5	A	A	5	Y	2	N/A	N/A	7	4
A	449	20-Mar-99	T-38	5	57.00	72.00	88.00	4	D	D	4	Y	2	N/A	N/A	6	3
A	449	20-Mar-99	T-38	6	35.00	60.00	80.00	5	A	A	5	Y	2	N/A	N/A	5	4
A	449	20-Mar-99	T-38	20	49.00	67.00	89.00	4	D	A	5	N	2	N/A	N/A	ND	ND
A	449	20-Mar-99	T-38	21	42.00	66.00	89.00	4	D	A	5	N	2	N/A	N/A	ND	ND
A	449	20-Mar-99	T-38	22	41.00	59.00	83.00	5	A	A	5	Y	2	N/A	N/A	ND	ND
B	447	19-Mar-99	T-38	3	39.50	63.20	73.70	5	A	A	5	Y	1	N/A	N/A	7	3
B	447	19-Mar-99	T-38	4	36.80	73.70	86.80	5	A	A	5	Y	1	N/A	N/A	7	3
B	447	19-Mar-99	T-38	5	52.60	81.60	92.10	3	D	D	3	Y	1	N/A	N/A	7	4
C	446	19-Mar-99	T-38	2	29.0	54.8	77.4	6	A	A	6	Y	3	N/A	N/A	7	3
C	446	19-Mar-99	T-38	3	45.2	54.8	77.4	6	A	A	6	Y	3	N/A	N/A	6	4
C	446	19-Mar-99	T-38	4	50.0	73.3	90.0	5	A	D	4	N	3	N/A	N/A	6	4
A	448	20-Mar-99	Hi-fi	3	5.63	29.34	63.75	7	Not A	Not A	7	Y	3	8	4	7	4
A	448	20-Mar-99	Hi-fi	4	16.62	41.00	66.21	6	A	Not A	7	N	3	8	4	8	4
A	448	20-Mar-99	Hi-fi	5	21.60	43.60	75.20	5	A	Not A	7	N	2	8	4	8	4
A	448	20-Mar-99	Hi-fi	6	20.01	43.70	70.06	5	A	Not A	7	N	2	8	4	6	3
A	448	20-Mar-99	Hi-fi	7	12.53	41.70	80.00	5	A	Not A	7	N	2	8	3	7	4
A	448	20-Mar-99	Hi-fi	31	No data (ND)	ND	ND	5	ND	ND	ND	N/A	2	ND	ND	ND	ND
A	453	26-Mar-99	Hi-fi	20	ND	ND	ND	5	A	ND	ND	N/A	3	5	3	7	4
B	445	18-Mar-99	Hi-fi	3	28.06	49.35	68.22	5	A	Not A	7	N	2	8	4	8	4
B	445	18-Mar-99	Hi-fi	4	16.53	48.34	79.98	6	A	Not A	7	N	2	8	4	8	4
B	445	18-Mar-99	Hi-fi	5	15.89	51.13	80.65	6	A	A	6	Y	2	Not Able	4	8	4
B	445	18-Mar-99	Hi-fi	6	14.40	48.21	82.31	6	A	Not A	7	N	2	Not Able	4	8	4
B	452	23-Mar-99	Hi-fi	26	ND	ND	ND	5	A	ND	ND	N/A	1	ND	ND	ND	ND
C	444	18-Mar-99	Hi-fi	3	10.74	32.11	79.15	6	A	Not A	7	N	3	8	4	7	3
C	444	18-Mar-99	Hi-fi	4	6.55	23.76	78.43	6	A	Not A	7	N	3	8	4	8	4
C	444	18-Mar-99	Hi-fi	5	7.96	25.44	71.76	5	A	Not A	7	N	3	8	4	8	4
C	444	18-Mar-99	Hi-fi	6	10.56	24.33	77.15	7	Not A	Not A	7	Y	3	Not Able	4	8	4

Table E3 (Concluded)
PHASE 3 OPERATIONAL TRACKING FOR BASELINE FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record No.	5 Mil (pct)	10 Mil (pct)	25 Mil (pct)	Pilot CHR	PEP	APP	Adj. Rating	Agree?	Pilot PIOR	R. Smith CHR	R. Smith PIOR	R. Smith VFR CHR	R. Smith VFR PIOR
C	451	23-Mar-99	Hi-fi	22	ND	ND	ND	5	A	ND	ND	N/A	3	6	4	7	4
A	453	26-Mar-99	Lo-fi	3	58.83	81.95	95.33	4	D	D	4	Y	2	Not Able	2	7	4
A	453	26-Mar-99	Lo-fi	4	56.81	82.13	95.91	4	D	D	4	Y	2	Not Able	4	6	3
A	453	26-Mar-99	Lo-fi	5	55.44	81.99	95.33	3	D	D	3	Y	2	7	4	7	4
B	452	23-Mar-99	Lo-fi	4	57.41	81.27	94.83	3	D	D	3	Y	1	8	4	6	3
B	452	23-Mar-99	Lo-fi	5	64.08	82.45	93.64	3	D	D	3	Y	1	8	4	6	3
B	452	23-Mar-99	Lo-fi	6	64.89	84.24	95.17	3	D	D	3	Y	1	Not Able	4	7	4
C	451	23-Mar-99	Lo-fi	5	65.96	82.61	96.56	3	D	D	3	Y	2	7	4	6	3
C	451	23-Mar-99	Lo-fi	6	66.60	84.13	95.95	2	D	D	2	Y	2	8	4	6	3
C	451	23-Mar-99	Lo-fi	7	64.03	85.11	95.72	2	D	D	2	Y	2	8	4	6	3

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number, used for data reduction
3. Date - Date mission was flown
4. Target - Target type [T-38A, high-fidelity (hi-fi) head-up display (HUD) task, or low-fidelity (lo-fi) HUD task]
5. Record - Record number, used for data reduction
6. 5 mil - Percent of time target was within 5 mil circle
7. 10 mil - Percent of time target was within 10 mil circle
8. 25 mil - Percent of time target was within 25 mil circle
9. Pilot CHR - Pilot designated Cooper-Harper Rating (CHR) (airborne)
10. PEP - Pilot estimated performance (PEP) (desired/adequate/neither – D/A/N) given while airborne
11. APP - Actual pilot performance (APP) (desired/adequate/neither - D/A/N) given after data reduction
12. Adj. Rating - Adjusted rating, maximum pilot CHR that could be given with actual pilot performance
13. Agree? - Did pilot estimated performance and actual pilot performance agree?
14. Pilot PIOR - Pilot designated pilot-induced oscillation rating (PIOR) (airborne)
15. R. Smith CHR - CHR derived using R. Smith criteria, using HUD error signal
16. R. Smith PIOR - PIOR derived using R. Smith criteria, using HUD error signal
17. R. Smith VFR CHR - CHR derived using R. Smith criteria, not using HUD error signal
18. R. Smith VFR PIOR - PIOR derived using R. Smith criteria, not using HUD error signal

Table E4

FREQUENCY SWEEPS FOR SENSITIVE STICK FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Record	R. Smith CHR	R. Smith PIOR
A	448	20 Mar 99	25	ND	ND
A	453	26 Mar 99	26	7	4
B	445	18 Mar 99	21	7	4
B	452	23 Mar 99	33	ND	ND
C	446	19 Mar 99	15	6	3
C	451	23 Mar 99	28	6	3

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number
3. Date - Date mission was flown
4. Record - Record number, used for data reduction
5. R. Smith VFR CHR - Cooper-Harper Rating using R. Smith criteria not using head-up display (HUD) error signal
6. R. Smith VFR PIO - PIOR using R. Smith criteria not using HUD error signal

Table E5

PHASE 2 HANDLING QUALITIES DURING TRACKING (HQDT) SENSITIVE STICK FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record	HQDT Type	Pilot PIOR	R. Smith PIOR	R. Smith VFR PIOR
A	449	20 Mar 99	T-38	8	Small/Large Amp.	4	N/A	4
B	447	19 Mar 99	T-38	7	Prop. Amp.	2	N/A	3
B	447	19 Mar 99	T-38	16	Prop. Amp.	3	N/A	3
B	447	19 Mar 99	T-38	22	Prop. Amp.	3	N/A	3
C	446	19 Mar 99	T-38	5	Small/Large Amp.	5	N/A	4
A	448	20 Mar 99	Hi-fi	9	Small/Large Amp.	4	4	4
A	448	20 Mar 99	Hi-fi	29	Small/Large Amp.	4	ND	ND
A	453	26 Mar 99	Hi-fi	17	Small Amp.	4	3	3
A	453	26 Mar 99	Hi-fi	17	Large Amp.	5	3	2
A	453	26 Mar 99	Hi-fi	18	Prop. Amp.	4	4	4
B	445	18 Mar 99	Hi-fi	8	Prop. Amp.	3	4	4
B	452	23 Mar 99	Hi-fi	20	Small Amp.	3	ND	ND
B	452	23 Mar 99	Hi-fi	21	Large Amp.	3	ND	ND
B	452	23 Mar 99	Hi-fi	22	Prop. Amp.	1	ND	ND
C	444	18 Mar 99	Hi-fi	8	Prop. Amp.	5	4	4
C	451	23 Mar 99	Hi-fi	19	Small Amp.	5	4	3
C	451	23 Mar 99	Hi-fi	19	Large Amp.	5	3	4
C	451	23 Mar 99	Hi-fi	20	Prop. Amp.	5	4	4
A	453	26 Mar 99	Lo-fi	7	Small/Large Amp.	4	4	3
B	452	23 Mar 99	Lo-fi	8	Prop. Amp.	4	4	3
C	451	23 Mar 99	Lo-fi	9	Small/Large Amp.	5	3	4

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number, used for data reduction
3. Date - Date mission was flown
4. Target - Target type [T-38A, high-fidelity head-up display(HUD) task (hi-fi), or low-fidelity HUD task (lo-fi)]
5. Record - Record number, used for data reduction)
6. HQDT Type - Handling qualities during tracking (HQDT) type (small const. amp., large const. amp., proportional amp.)
7. Pilot PIOR - Pilot designated pilot-induced oscillation rating (PIOR) (airborne)
8. R. Smith PIOR - PIOR derived using R. Smith criteria
9. R. Smith VFR PIOR - PIOR derived using R. Smith criteria, not using HUD error signal

Table E6
PHASE 3 OPERATIONAL TRACKING FOR SENSITIVE STICK FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record No.	5 Mil (pct)	10 Mil (pct)	25 Mil (pct)	Pilot CHR	PEP	APP	Adj. Rating	Agree?	Pilot PIOR	R. Smith CHR	R. Smith PIOR	R. Smith VFR CHR	R. Smith VFR PIOR
A	449	20 Mar 99	T-38	9	18.00	45.00	84.00	6	A	Not A	7	N	4	N/A	N/A	5	2
A	449	20 Mar 99	T-38	11	37.00	66.00	82.00	6	A	A	6	Y	4	N/A	N/A	8	4
A	449	20 Mar 99	T-38	12	48.00	63.00	88.00	5	A	A	5	Y	3	N/A	N/A	8	4
A	449	20 Mar 99	T-38	13	32.00	53.00	76.00	5	A	A	5	Y	4	N/A	N/A	7	4
B	447	19 Mar 99	T-38	8	61.40	90.90	97.70	5	A	D	4	N	1	N/A	N/A	4	2
B	447	19 Mar 99	T-38	9	43.90	78.00	92.70	5	A	A	5	Y	2	N/A	N/A	6	3
B	447	19 Mar 99	T-38	10	74.40	84.60	94.90	3	D	D	3	Y	1	N/A	N/A	4	2
C	446	19 Mar 99	T-38	6	41.90	61.20	77.40	6	A	A	6	Y	5	N/A	N/A	8	4
C	446	19 Mar 99	T-38	7	32.20	54.80	80.60	5	A	A	5	Y	5	N/A	N/A	6	3
C	446	19 Mar 99	T-38	8	54.50	81.80	94.00	4	D	D	4	Y	5	N/A	N/A	7	4
A	448	20 Mar 99	Hi-fi	10	8.78	28.00	79.53	7	Not A	Not A	7	Y	4	8	4	8	4
A	448	20 Mar 99	Hi-fi	11	16.17	48.30	76.16	6	A	Not A	7	N	3	9	4	8	4
A	448	20 Mar 99	Hi-fi	12	20.57	46.31	85.18	6	A	Not A	7	N	3	9	4	7	2
A	448	20 Mar 99	Hi-fi	13	9.64	31.77	75.24	7	Not A	Not A	7	Y	4	8	4	8	4
A	448	20 Mar 99	Hi-fi	14	15.99	46.77	80.16	6	A	Not A	7	N	3	8	3	7	3
A	453	26 Mar 99	Hi-fi	21	No data (ND)	ND	ND	6	A	ND	ND	N/A	4	9	4	8	4
B	445	18 Mar 99	Hi-fi	9	17.48	43.79	78.54	8	Not A	Not A	8	Y	3	8	3	8	4
B	445	18 Mar 99	Hi-fi	10	14.20	45.02	84.15	8	Not A	Not A	8	Y	3	9	4	8	4
B	445	18 Mar 99	Hi-fi	11	20.05	61.10	84.08	6	A	A	6	Y	3	8	3	8	2
B	445	18 Mar 99	Hi-fi	12	21.17	62.70	87.13	5	A	A	5	Y	2	4	2	4	2
B	452	23 Mar 99	Hi-fi	27	ND	ND	ND	6	A	ND	ND	N/A	3	8	4	ND	ND
C	444	18 Mar 99	Hi-fi	9	5.42	17.95	66.82	8	Not A	Not A	8	Y	5	9	4	8	4
C	444	18 Mar 99	Hi-fi	10	4.00	14.21	68.40	7	Not A	Not A	7	Y	5	8	3	8	4
C	444	18 Mar 99	Hi-fi	12	7.04	28.72	76.03	7	Not A	Not A	7	Y	5	8	4	8	4
C	444	18 Mar 99	Hi-fi	13	9.68	27.07	74.92	7	Not A	Not A	7	Y	5	7	3	7	4
C	444	18 Mar 99	Hi-fi	14	7.89	23.65	73.70	7	Not A	Not A	7	Y	5	8	4	6	3
C	451	23 Mar 99	Hi-fi	23	ND	ND	ND	6	A	ND	ND	N/A	5	9	3	8	4
A	453	26 Mar 99	Lo-fi	8	47.00	73.95	95.49	5	A	D	4	N	3	8	4	8	4
A	453	26 Mar 99	Lo-fi	9	52.67	77.35	96.13	4	D	D	4	Y	3	7	4	7	4
A	453	26 Mar 99	Lo-fi	10	52.49	76.80	95.56	3	D	D	3	Y	3	6	4	6	4
B	452	23 Mar 99	Lo-fi	9	66.03	83.08	95.28	4	D	D	4	Y	3	Not Able	4	6	4
B	452	23 Mar 99	Lo-fi	10	60.83	83.68	95.79	4	D	D	4	Y	3	Not Able	4	8	4

Table E6 (Concluded)
PHASE 3 OPERATIONAL TRACKING FOR SENSITIVE STICK FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record No.	5 Mil (pct)	10 Mil (pct)	25 Mil (pct)	Pilot CHR	PEP	APP	Adj. Rating	Agree?	Pilot PIOR	R. Smith CHR	R. Smith PIOR	R. Smith VFR CHR	R. Smith VFR PIOR
B	452	23 Mar 99	Lo-fi	11	63.93	85.49	96.16	4	D	D	4	Y	3	Not Able	4	6	3
C	451	23 Mar 99	Lo-fi	10	56.81	82.69	96.59	4	D	D	4	Y	5	Not Able	4	7	4
C	451	23 Mar 99	Lo-fi	11	65.05	84.11	95.68	4	D	D	4	Y	5	Not Able	4	7	4
C	451	23 Mar 99	Lo-fi	12	63.07	85.51	96.72	3	D	D	3	Y	5	8	4	7	3

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number, used for data reduction
3. Date - Date mission was flown
4. Target - Target type [T-38A, high-fidelity (hi-fi) head-up display (HUD) task, or low-fidelity (lo-fi) HUD task]
5. Record - Record number, used for data reduction
6. 5 mil - Percent of time target was within 5 mil circle
7. 10 mil - Percent of time target was within 10 mil circle
8. 25 mil - Percent of time target was within 25 mil circle
9. Pilot CHR - Pilot designated Cooper-Harper Rating (CHR) (airborne)
10. PEP - Pilot estimated performance (PEP) (desired/adequate/neither – D/A/N) given while airborne
11. APP - Actual pilot performance (APP) (desired/adequate/neither - (D/A/N) given after data reduction
12. Adj. Rating - Adjusted rating, maximum pilot CHR that could be given with actual pilot performance
13. Agree? - Did pilot estimated performance and actual pilot performance agree?
14. Pilot PIOR - Pilot designated pilot-induced oscillation rating (PIOR) (airborne)
15. R. Smith CHR - CHR derived using R. Smith criteria, using HUD error signal
16. R. Smith PIOR - PIOR derived using R. Smith criteria, using HUD error signal
17. R. Smith VFR CHR - CHR derived using R. Smith criteria, not using HUD error signal
18. R. Smith VFR PIOR - PIOR derived using R. Smith criteria, not using HUD error signal

Table E7

FREQUENCY SWEEPS FOR TIME DELAY FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Record	R. Smith VFR CHR	R. Smith VFR PIOR
Pilot A	448	20 Mar 99	27	ND	ND
Pilot A	453	26 Mar 99	28	9	4
Pilot B	445	18 Mar 99	23	9	4
Pilot B	452	23 Mar 99	35	ND	ND
Pilot C	451	23 Mar 99	29	9	4
Pilot C	446	19 Mar 99	16	9	4

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number, used for data reduction
3. Date - Date mission was flown
4. Record - Record number, used for data reduction
5. R. Smith VFR CHR - Coorper-Harper rating (CHR) derived using R. Smith criteria, not using HUD error signal
6. R. Smith VFR PIOR - Pilot-induced oscillation rating (PIOR) derived using R. Smith criteria, not using HUD error signal

Table E8

PHASE 2 HANDLING QUALITIES DURING TRACKING (HQDT), TIME DELAY FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record	HQDT Type	Pilot PIOR	R. Smith PIOR	R. Smith VFR PIOR
A	449	20 Mar 99	T-38	15	Const. Amp.	5	N/A	4
B	447	19 Mar 99	T-38	11	Prop. Amp.	5	N/A	4
B	447	19 Mar 99	T-38	17	Prop. Amp.	5	N/A	4
B	447	19 Mar 99	T-38	23	Prop. Amp.	5	N/A	4
C	446	19 Mar 99	T-38	9	Const. Amp.	4	N/A	4
A	448	20 Mar 99	Hi-fi	16	Const. Amp.	5	4	4
A	448	20 Mar 99	Hi-fi	30	Const. Amp.	5	No data (ND)	ND
A	453	26 Mar 99	Hi-fi	19	Small Amp.	3	4	4
A	453	26 Mar 99	Hi-fi	19	Large Amp.	5	4	4
A	453	26 Mar 99	Hi-fi	19	Prop. Amp.	5	4	4
B	445	18 Mar 99	Hi-fi	15	Prop. Amp.	6	4	4
B	452	23 Mar 99	Hi-fi	23	Small Amp.	4	ND	ND
B	452	23 Mar 99	Hi-fi	24	Large Amp.	4	ND	ND
B	452	23 Mar 99	Hi-fi	25	Prop. Amp.	5	ND	ND
C	444	18 Mar 99	Hi-fi	15	Const. Amp.	4	4	4
C	451	23 Mar 99	Hi-fi	21	Small Amp.	4	4	4
C	451	23 Mar 99	Hi-fi	21	Large Amp.	4	4	4
C	451	23 Mar 99	Hi-fi	21	Prop. Amp.	4	4	4
A	453	26 Mar 99	Lo-fi	12	Const. Amp.	4	4	4
B	452	23 Mar 99	Lo-fi	13	Prop. Amp.	4	4	4
C	451	23 Mar 99	Lo-fi	14	Const. Amp.	4	4	4

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number, used for data reduction
3. Date - Date mission was flown
4. Target - Target type [T-38A, high-fidelity (hi-fi) head-up display (HUD) task, or low-fidelity (lo-fi) HUD task]
5. Record - Record number, used for data reduction
6. HQDT Type - Handling qualitites during tracking (HQDT) (Small const. amp., large const. amp., proportional amp.)
7. Pilot PIOR - Pilot designated pilot-induced oscillation rating (PIOR) (airborne)
8. R. Smith VFR PIOR - PIOR derived using R. Smith criteria, not using HUD error signal
9. R. Smith PIOR - PIOR derived using R. Smith criteria, using HUD error signal

Table E9
PHASE 3 OPERATIONAL TRACKING FOR TIME DELAY FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record No.	5 Mil (pct)	10 Mil (pct)	25 Mil (pct)	Pilot CHR	PEP	APP	Adj. Rating	Agree?	Pilot PIOR	R. Smith CHR	R. Smith PIOR	R. Smith VFR CHR	R. Smith VFR PIOR
A	449	20 Mar 99	T-38	16	13.00	33.00	83.00	7	Not A	Not A	7	Y	3	N/A	N/A	9	4
A	449	20 Mar 99	T-38	17	19.00	35.00	78.00	7	Not A	Not A	7	Y	4	N/A	N/A	No data (ND)	ND
A	449	20 Mar 99	T-38	18	28.00	50.00	82.00	6	A	A	6	Y	3	N/A	N/A	ND	ND
A	449	20 Mar 99	T-38	19	22.00	60.00	85.00	5	A	A	5	Y	3	N/A	N/A	ND	ND
B	447	19 Mar 99	T-38	12	38.50	74.40	89.70	7	Not A	A	6	N	3	N/A	N/A	9	4
B	447	19 Mar 99	T-38	13	41.50	78.00	95.10	6	A	A	6	Y	3	N/A	N/A	9	4
B	447	19 Mar 99	T-38	14	44.70	76.30	89.50	5	A	A	5	Y	3	N/A	N/A	9	4
C	446	19 Mar 99	T-38	10	26.50	67.60	91.10	7	Not A	A	6	N	3	N/A	N/A	9	4
C	446	19 Mar 99	T-38	11	27.20	69.70	90.90	6	A	A	6	Y	3	N/A	N/A	9	4
C	446	19 Mar 99	T-38	12	24.00	60.00	88.00	5	A	A	5	Y	3	N/A	N/A	9	4
C	446	19 Mar 99	T-38	13	28.90	71.10	94.70	8	Not A	A	6	N	3	N/A	N/A	9	4
A	448	20 Mar 99	Hi-fi	17	15.40	43.45	74.11	7	Not A	Not A	7	Y	4	9	4	9	4
A	448	20 Mar 99	Hi-fi	18	18.59	45.17	75.83	6	A	Not A	7	N	3	9	4	9	4
A	448	20 Mar 99	Hi-fi	19	29.42	50.74	78.45	5	A	A	5	Y	2	9	4	9	4
A	448	20 Mar 99	Hi-fi	20	13.37	40.10	81.45	6	A	Not A	7	N	4	9	4	9	4
A	448	20 Mar 99	Hi-fi	21	12.97	33.36	72.26	7	Not A	Not A	7	Y	4	9	4	9	4
A	453	26 Mar 99	Hi-fi	22	ND	ND	ND	7	Not A	ND	ND	N/A	4	8	4	9	4
B	445	18 Mar 99	Hi-fi	16	5.71	19.64	48.14	10	Not A	Not A	10	Y	6	9	4	9	4
B	445	18 Mar 99	Hi-fi	17	6.92	19.62	57.12	10	Not A	Not A	10	Y	6	9	4	9	4
B	445	18 Mar 99	Hi-fi	18	3.48	14.26	57.06	9	Not A	Not A	9	Y	4	10	4	9	4
B	445	18 Mar 99	Hi-fi	19	5.48	20.84	66.74	9	Not A	Not A	9	Y	4	10	4	9	4
B	452	23 Mar 99	Hi-fi	28	ND	ND	ND	7	Not A	ND	ND	N/A	3	ND	ND	ND	ND
C	444	18 Mar 99	Hi-fi	16	12.72	32.79	76.53	6	A	Not A	7	N	4	8	4	8	4
C	444	18 Mar 99	Hi-fi	17	7.25	30.46	65.31	7	Not A	Not A	7	Y	4	9	4	8	4
C	444	18 Mar 99	Hi-fi	18	14.93	37.11	71.06	6	A	Not A	7	N	4	9	4	9	4
C	444	18 Mar 99	Hi-fi	19	4.59	17.59	72.05	8	Not A	Not A	8	Y	4	9	4	8	4
C	444	18 Mar 99	Hi-fi	20	10.81	31.32	73.58	6	A	Not A	7	N	4	9	4	9	4
C	451	23 Mar 99	Hi-fi	24	ND	ND	ND	7	Not A	ND	ND	N/A	4	8	4	8	4
A	453	26 Mar 99	Lo-fi	13	40.95	66.31	91.49	6	A	D	4	N	4	9	4	9	4
A	453	26 Mar 99	Lo-fi	14	45.01	70.29	94.00	4	D	D	4	Y	3	9	4	9	4
A	453	26 Mar 99	Lo-fi	15	42.59	69.47	93.56	4	D	D	4	Y	4	9	4	9	4

Table E9 (Concluded)
PHASE 3 OPERATIONAL TRACKING FOR TIME DELAY FLIGHT CONTROL CONFIGURATION (FCC)

Pilot	Mission	Date	Target	Record No.	5 Mil (pct)	10 Mil (pct)	25 Mil (pct)	Pilot CHR	PEP	APP	Adj. Rating	Agree?	Pilot PIOR	R. Smith CHR	R. Smith PIOR	R. Smith VFR CHR	R. Smith VFR PIOR
B	452	23 Mar 99	Lo-fi	14	42.53	70.44	90.96	6	A	D	4	N	3	9	4	9	4
B	452	23 Mar 99	Lo-fi	15	ND	ND	ND	4	D	ND	ND	N/A	3	ND	ND	ND	ND
B	452	23 Mar 99	Lo-fi	16	ND	ND	ND	4	D	ND	ND	N/A	3	ND	ND	ND	ND
C	451	23 Mar 99	Lo-fi	15	42.81	68.08	93.05	5	A	D	4	N	4	9	4	9	4
C	451	23 Mar 99	Lo-fi	16	47.16	73.69	93.28	4	D	D	4	Y	4	9	4	9	4
C	451	23 Mar 99	Lo-fi	17	43.19	72.68	94.36	4	D	D	4	Y	4	9	4	9	4

Notes:
1. Pilot - Pilot who flew mission
2. Mission - Calspan designated mission number, used for data reduction
3. Date - Date mission was flown
4. arget - Target type [T-38A, high-fidelity (hi-fi) head-up display (HUD) task, or low-fidelity (lo-fi) HUD task]
5. Record - Record number, used for data reduction
6. 5 mil - Percent of time target was within 5 mil circle
7. 10 mil - Percent of time target was within 10 mil circle
8. 25 mil - Percent of time target was within 25 mil circle
9. Pilot CHR - Pilot designated Cooper-Harper Rating (CHR) (airborne)
10. PEP - Pilot estimated performance (PEP) (desired/adequate/neither - D/A/N) given while airborne
11. APP - Actual pilot performance (APP) (desired/adequate/neither – D/A/N) given after data reduction
12. Adj. Rating - Adjusted rating, maximum pilot CHR that could be given with actual pilot performance
13. Agree? - Did pilot estimated performance and actual pilot performance agree?
14. Pilot PIOR - Pilot designated pilot-induced oscillation rating (PIOR) (airborne)
15. R. Smith CHR - CHR derived using R. Smith criteria, using HUD error signal
16. R. Smith PIOR - PIOR derived using R. Smith criteria, using HUD error signal
17. R. Smith VFR CHR - CHR derived using R. Smith criteria, not using HUD error signal
18 R. Smith VFR PIOR - PIOR derived using R. Smith criteria, not using HUD error signal

APPENDIX F

FIGURES

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FIGURES

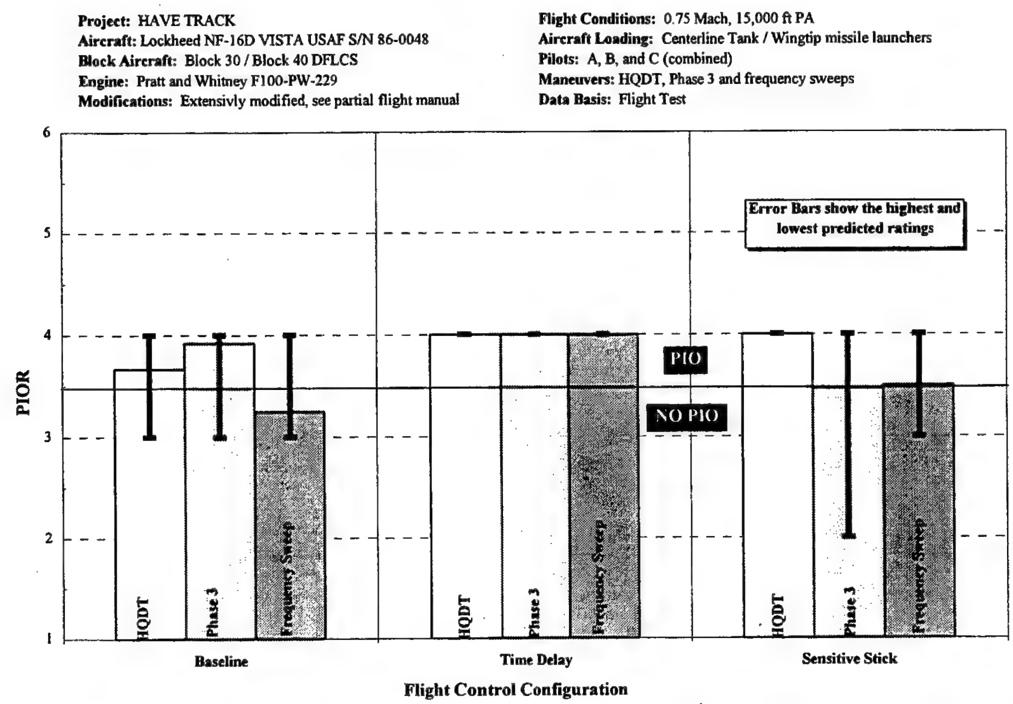

Figure F1 Comparison of Pilot-Induced Oscillation Ratings (PIORs) Produced by R. Smith Criteria, High-Fidelity Head-Up Display (HUD) Target

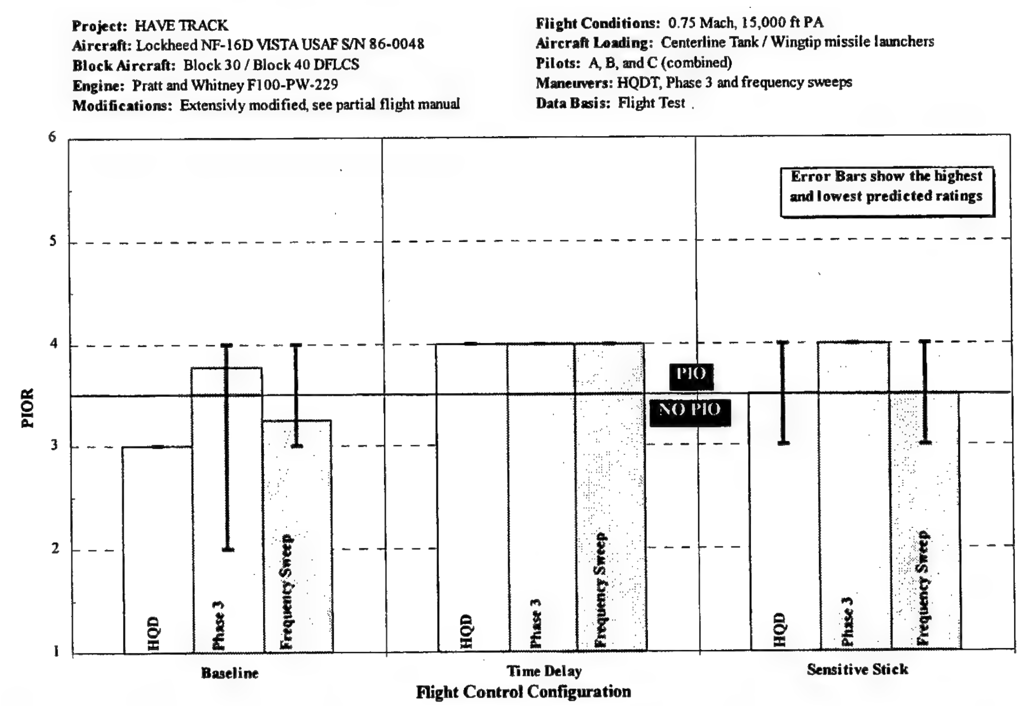

Figure F2 Comparison of Pilot-Induced Oscillation Ratings (PIORs) Produced by R. Smith Criteria, Low-Fidelity Head-Up Display (HUD) Target

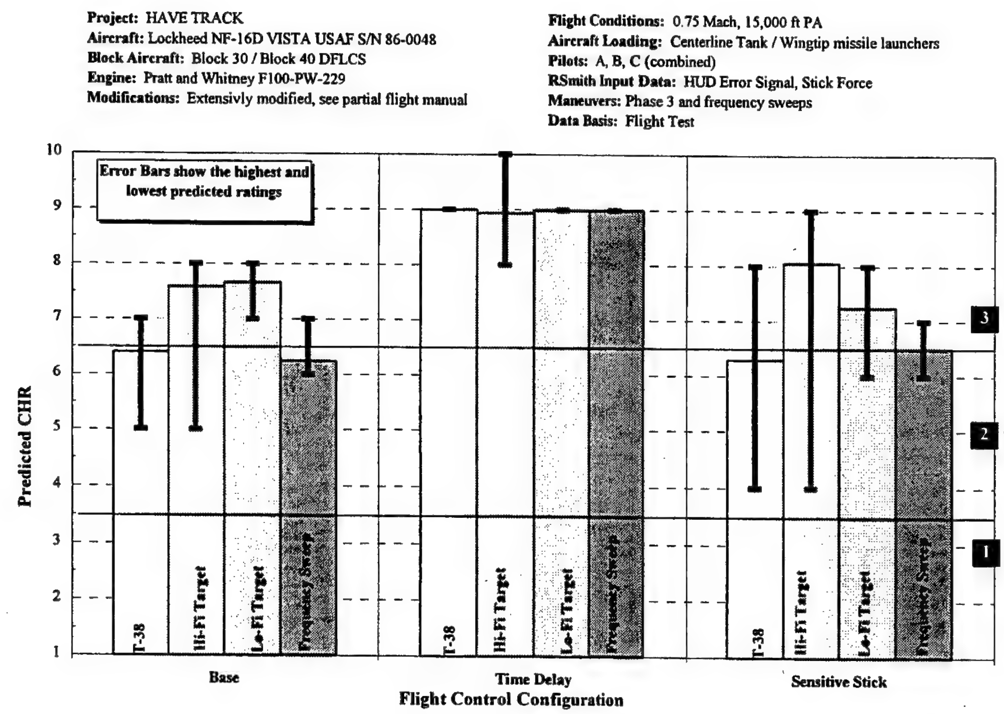

Figure F3 Comparison of Cooper-Harper Ratings (CHRs) Obtained From the R. Smith Program, Head-Up Display (HUD) Error Signal Analysis

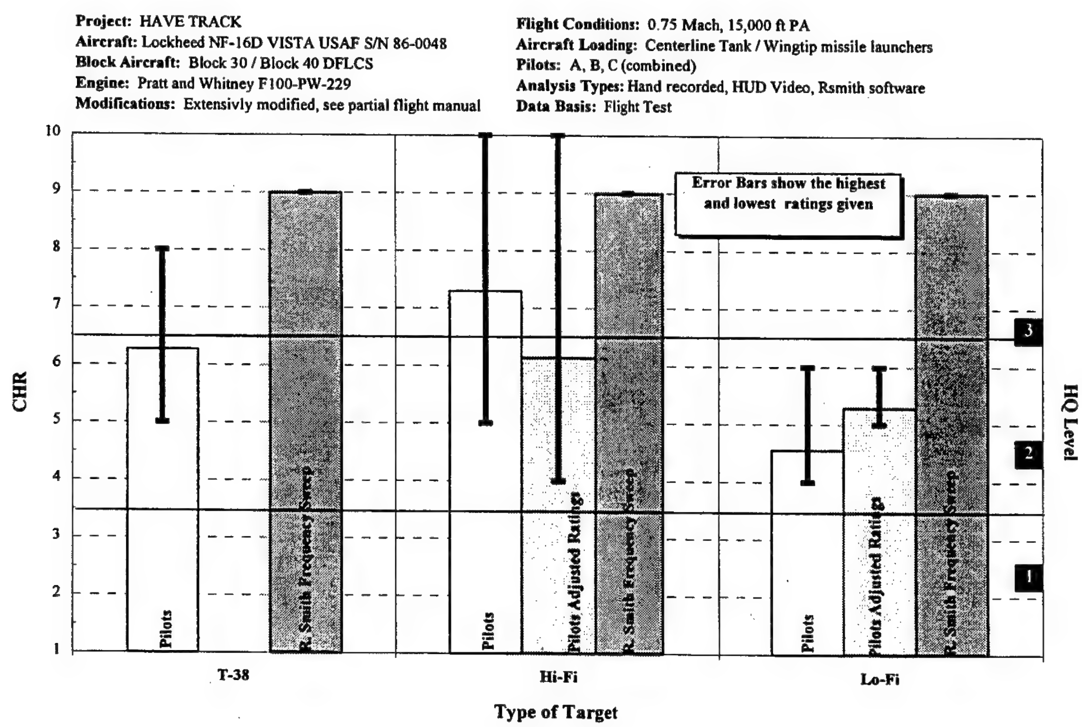

Figure F4 Comparison of Cooper-Harper Ratings (CHRs) Obtained From Pilot Ratings and R. Smith Program, Time Delay Flight Control Configuration (FCC)

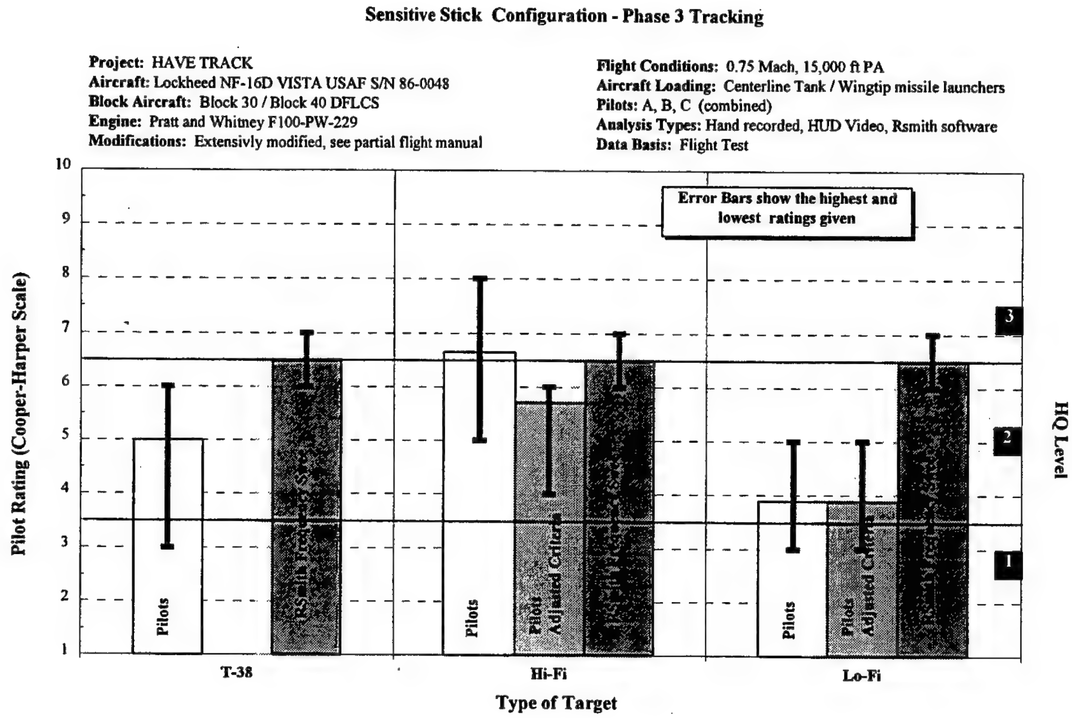

Figure F5 Comparison of Cooper-Harper Ratings (CHRs) Obtained From Pilot Ratings and R. Smith Program, Sensitive Stick Flight Control Configuration (FCC)

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APPENDIX G

SPECIALIZED HANDLING QUALITIES DURING TRACKING TECHNIQUE

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SPECIALIZED HANDLING QUALITIES DURING TRACKING (HQDT) TECHNIQUE

In general, handling qualities during tracking (HQDT) are designed to root out any potential poor handling qualities (HQ) associated with 'high bandwidth' pilot inputs. During operational task evaluations, pilot compensation techniques can hide these poor HQ by applying shaped inputs at a lower bandwidth. A higher pilot bandwidth could result in potential pilot-induced oscillations (PIO) if the aircraft open loop phase margin is sufficiently small at the higher frequency. Pilots may not recognize the onset of PIO susceptibility as the transition from compensated lower frequency inputs to higher frequency inputs is not smooth. Five intuitive hypotheses of pilot dynamics are as follows:

1. In order to experience and evaluate airplane HQ, the pilot must track a reference signal.

2. HQ are closely related to pilot bandwidth.

3. Pilot's track only when an error signal exceeds a tracking threshold.

4. When tracking becomes necessary, experienced pilots adopt the lowest bandwidth piloting technique that is consistent with reasonable task performance.

5. Pilot's switch to a high bandwidth piloting technique when their level of excitement or anxiety exceeds a certain threshold.

Obviously, more difficult tasks will require greater pilot bandwidth or control gains to track the task, unless the allowable error or threshold is also proportionally increased. Thus, handling quality ratings are heavily influenced by the design task and the associated threshold. For a design task, the threshold can be specified as maintaining an average error size or maintaining the error within an absolute limit. The HQ associated with these two types of thresholds can be radically different. Tracking tasks with an absolute limit tend to induce the greatest anxiety or level of excitement. In the example of an aircraft flaring for landing, the pitch control task can have two limits: incomplete flare and a subsequent hard landing or a high flare with a drop-in and subsequent hard landing. The psychological aspects are not discussed herein, but there are other examples where high bandwidth inputs are employed when fear is not the primary motivation. Sometimes, it can be frustration. In the example of the F-4 obtaining a gun solution over the skies of Vietnam, there were noticeable pitch oscillation bobbles as the pilot attempted to control the nose track to place as many bullets on the target as possible. Again, this was a target threshold absolute limit task, with the threshold limits being the tail and nose of the target aircraft. This example also illustrates another parameter that influences the pilot workload, namely time. Placing a time restriction on the given task forces the pilot to attain better performance in a more timely matter, especially where a gross acquisition was required.

The HQDT attempts to eliminate all these variables by directing zero error. This would require a precision aimpoint no larger than the size of the tracking pipper. Approximately 2-mil precision aimpoints are used, both for the head-up display (HUD) task and the T-38 target. For the T-38 target, the intersection of the trailing edge of the wing with the width of the fuselage is approximately 2 mils at 2,000 feet. To describe the required pilot technique, we'll use the definition of HQDT. "The HQDT piloting technique requires the evaluation pilot to aggressively track a precision aimpoint on a target, assiduously striving to correct even the smallest tracking errors as quickly as possible." Obviously, this definition leaves substantial room for interpretation from the pilot. Should the pilot shape his inputs, leading a reversal of input prior to the error going through zero? Should the pilot limit the size of his inputs, or should he adjust them based on the size of the error? How quickly should he move the controls as the error goes through zero? Again the overall goal of HQDT, is to examine pilot in the loop dynamics at his highest bandwidth, typically 8 to 10 rad/sec. As the pilot perceives numerous variables including position errors and their associated rates and accelerations, he can shape his inputs to accommodate an aircraft with poor HQ to minimize errors in a given tasks. This would require mental workload to reduce the physical workload or bandwidth of his inputs. According to hypothesis No. 4 above, this is natural for any pilot. However, this is exactly what HQDT tries to avoid. HQDT demands the pilot to be purely reactive, simply applying inputs based on perceived error with minimal mental compensation. HQDT is simply unnatural for any pilot unless his anxiety level pushes him to those type of high bandwidth inputs. Unfortunately, HQDT in of itself, does not illicit that sort of psychological motivation. Thus, for HQDT, the pilot has to

abandon those sort of natural pilot techniques, for a simple reactive technique of applying inputs. In addition, HQDT will often lead to degraded tracking performance compared to compensated pilot techniques. However, the intent of HQDT is not to determine the tracking performance when HQDT is applied. Rather, it's to determine if there is PIO susceptibility problem when the pilot applies high bandwidth inputs.

The three different evaluation pilots received the same training in HQDT piloting techniques. This consisted of Test Pilot School (TPS) course instruction and non motion simulator training with Mr. Ralph Smith. The written guidance for HQDT comes from TPS course notes authored by Mr. Tom Twisdale. Unfortunately, during HQDT evaluations, the HAVE TRACK pilots initially used slightly different HQDT techniques. Common to all the pilots was the requirement not to lead the reversal of pitch command relative to the error signal. Also, the pitch stick reversal was conducted at the highest rate possible. The difference in technique was largely in the magnitude of the stick inputs. Pilot C used set step inputs, building up the size of these step inputs slowly, to record 20 seconds of data for data analysis purposes. Figures G1 and G2 show the small and large amplitude 'bang-bang' control stick inputs for HQDT. Notice that the stick reversal occurs after the error goes through zero. It can be seen from these two pairs of time traces that the error did not increase proportionally to the size of the inputs. The pilot would therefore assign this configuration a PIO assessment of 3 or better. The power spectral density (PSD) for the small and large amplitude inputs are similar except for the greater amplitude of the large amplitude inputs, Figure G4.

Pilots A and B adjusted the size of their stick inputs based on the size of the error or error rate. This gave a far better qualitative assessment of the PIO susceptibility of a configuration than the method used by Pilot C. However, it often resulted in safety trips after only a few reversals. Figure G4 shows the proportional gain HQDT time trace. The point of stick transition is difficult to determine since the pitch trim forces were not neutral, and there is not the period of constant stick force as in the constant amplitude HQDT. The proportional amplitude HQDT resulted in a PSD that was much closer to the PSDs of the phase 3 tracking tasks. This HQDT technique is therefore closer to an operational tracking technique, and therefore more normal for the pilot. The pilots found this HQDT technique easier to use for making PIO assessments. PIO susceptibility was reduced to determining if the pilot had to reduce or freeze his inputs due to PIO.

If the HQDT techniques were standardized, each pilot would be able to derive the same ratings for a given aircraft. The only difference would be the individual pilot's internal time delay.

A separate requirement for the pilot is to make an assessment of the PIO susceptibility of a configuration, i.e. when or if to freeze the stick in response to aircraft oscillation. This subjectivity can also lead to differences in PIORs. The pilot has to make the determination if his larger stick inputs cause error excursions that are larger than expected. If the pilot feels that his inputs do not, then the PIOR is 3 or better. If the pilot feels the error excursions tend to diverge, then the rating is 5. If the error response has stabilized into a bounded oscillation, a "bucking bronco," then the rating is 4. There can however be a fine distinction between these ratings, and it falls upon the pilot's judgment to make the PIOR. An attempt could be made to remove this subjectivity with the aid of a HUD target and error signal. An intelligent programmed test input (PTI) could be developed using the HUD error signal as feedback for the stick input with an appropriate, variable, human time delay applied. This could potentially remove some of the pilot judgment from the PIO assessment, and could be used to investigate PIO susceptibility in simulation.

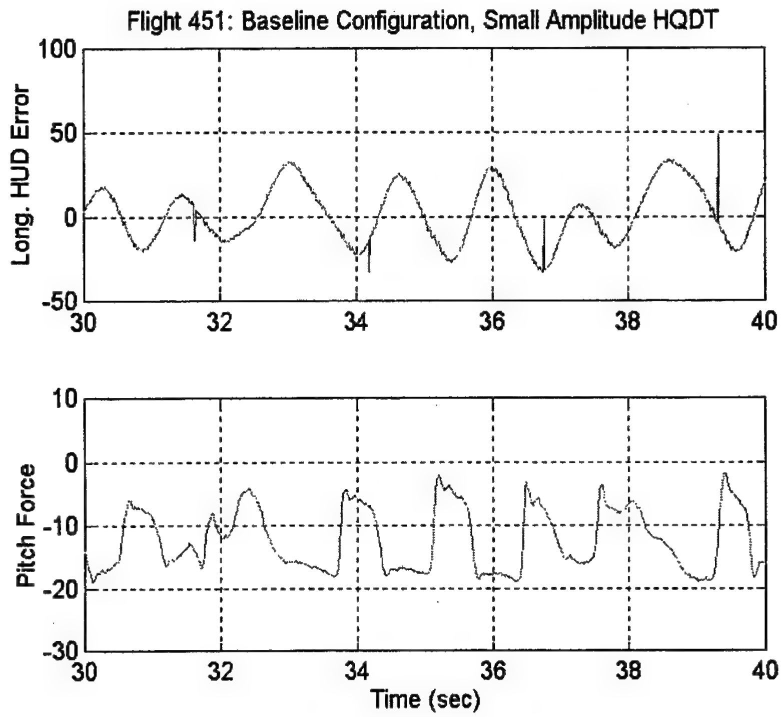

Figure G1 Small, Fixed Amplitude Handling Qualities During Tracking (HQDT)

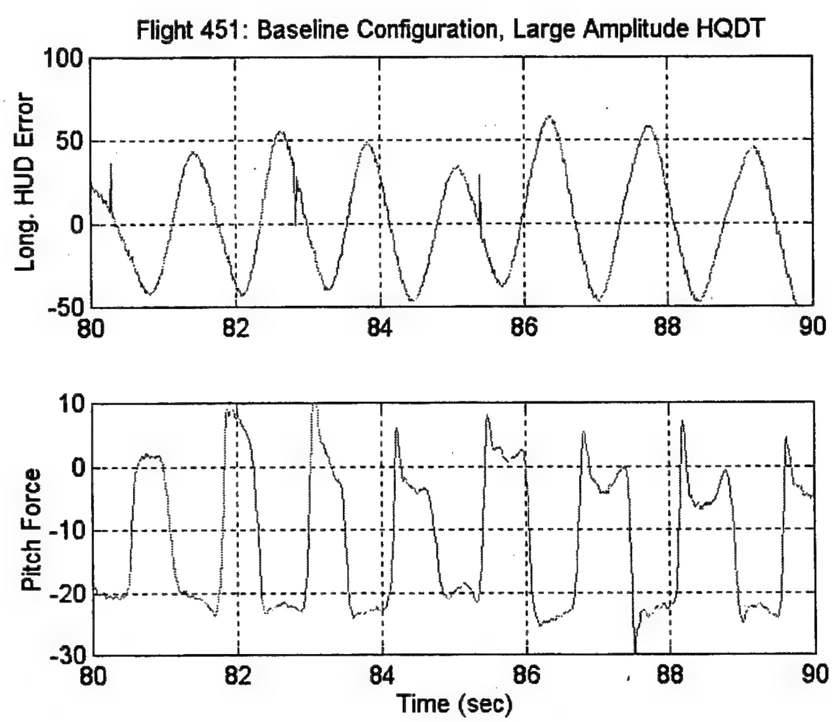

Figure G2 Large, Fixed Amplitude Handling Qualities During Tracking (HQDT)

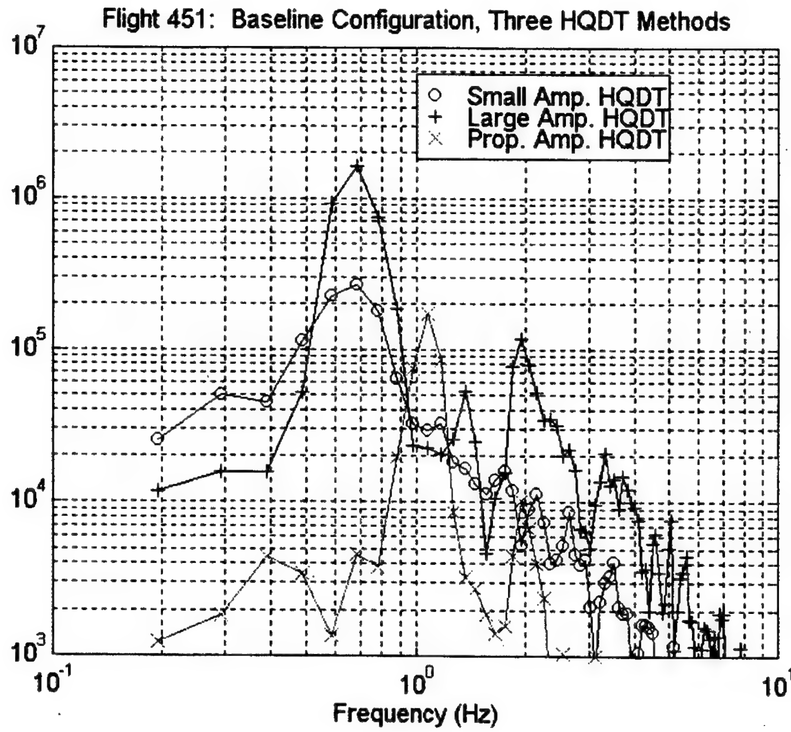

Figure G3 Flight 451: Power Spectral Density of Three Handling Qualities During Tracking (HQDT)

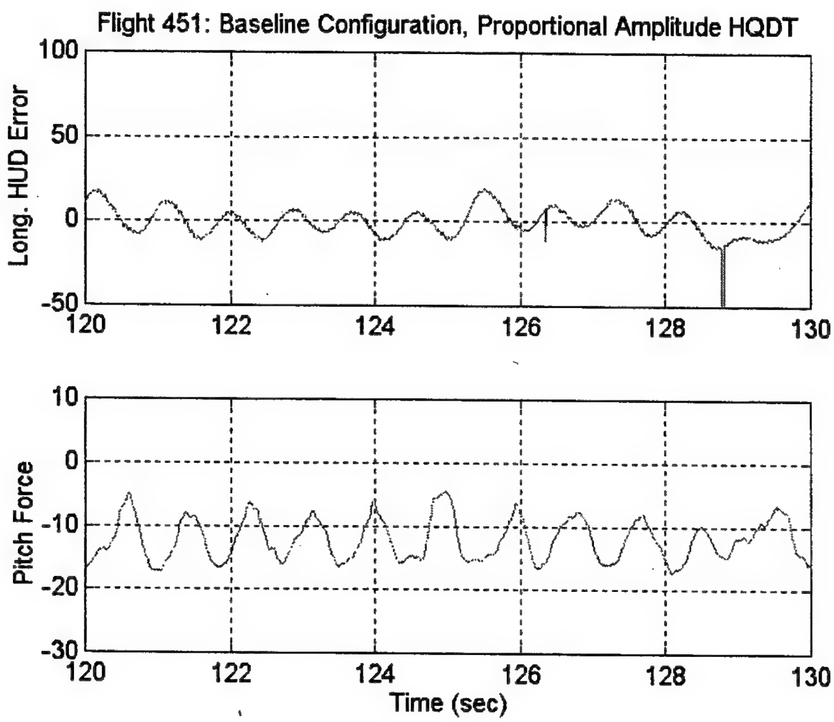

Figure G4 Proportional Amplitude Handling Qualities During Tracking (HQDT)

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition	Units
AFB	Air Force Base	---
AFFTC	Air Force Test Flight Center	---
AFRL	Air Force Research Lab	---
AOA	angle of attack	---
CHR	Cooper-Harper rating	---
FCC	flight control configuration	---
HQ	handling qualities	---
HQDT	handling qualities during tracking	---
HQR	handling qualities rating	---
HUD	head-up display	---
K_{TASK_PITCH}	pitch-axis tracking task gain	---
mil	milliradian	---
MIL-STD	Military Standard	---
MOA	military operating area	---
MOP	measures of performance	---
N/A	not applicable	---
ND	no data	---
PA	pressure altitude	---
PIO	pilot-induced oscillation	---
PIOR	pilot-induced oscillation rating	---
PSD	power spectral density	---
PTI	programmed test input	---
S/N	serial number	---
TPS	Test Pilot School	---
USAF	United States Air Force	---

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Concluded)

Abbreviation	Definition	Units
VFR	visual flight rules	---
VISTA	variable stability in-flight simulator test aircraft	---
VSS	variable stability system	---
p	roll rate	---
q	pitch rate	---
φ	roll angle	deg
θ	pitch angle	deg
α	angle of attack	---
N_z	normal acceleration	---

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